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Optimizing the Value Chain On Desktop Workstations

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On Desktop Workstations

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Abstract

We discuss developments in the theory and practice of integrated planning based on the concept of a company's value chain. We provide details of quantitative analyses performed on powerful new workstations using a data management and modeling system based on linear and mixed integer programming. The system employs spreadsheets, a fourth generation data management package, and a graphics package to support model data entry, reporting and maintenance. Our discussion includes an in-depth treatment of an integrated planning study in a consumer products company.

OPTIMIZING THE VALUE CHAIN ON DESKTOP WORKSTATIONS

by

Jeremy F. Shapiro, Vijay M. Singhal and Stephen N. Wagner

December 3, 1990

Introduction

About twenty years ago, managers began to sense that emerging information technologies could provide timely data which, when used to integrate diverse activities, would allow costs to be significantly reduced. In most companies, however, accomplishing integration proved elusive because harnessing the new technologies proved much more difficult than anticipated. Some firms have taken ten years, or more, to create and organize the data bases and computer infrastructure upon which to establish integrated planning and control.

This situation is changing radically. Many companies have finally assembled reasonably complete and accessible corporate information systems. As a result, managers are actively seeking new tools for analyzing their large, numerical data bases to identify strategies for reducing costs and improving competitive advantage.

The growing interest in integrated planning has been motivated in part from the "bottom-up" by logistics managers responsible for transportation, inventory management, warehousing, and other traditional functions, who perceive the potential improvements to be realized. Logistics practitioners refer to this approach as the integrated logistics management concept; see LaLonde et al [1970], Lambert and Mentzer [1980], or Magee, Copacino and Rosenfield [1985]. Ironically, strategic planners have reached the same conclusion from a "top-down" perspective. They have come to recognize that successful implementation of a strategic plan requires careful coordination of the company's activities at a detailed, operational level. Specifically, they suggest that design and analysis of operations be based on the value chain, a concept advanced by Porter [1985] which we discuss in more detail below.

We believe that increasing management attention to integrated planning offers exciting new opportunities for wider acceptance and use of operations research models. However, the models must be imbedded in easy to use decision support systems if they are to prove effective. Our premises in discussing these opportunities are:

- Mathematical programming provides a rich and powerful formalism for analyzing integrated planning problems;

- Recent advances in information technology, particularly in the computing power of microprocessors for desktop workstations, are fostering the development and use of advanced decision support systems for integrated planning based on mathematical programming models;

- Use of these advanced decision support systems can significantly improve a company's competitive advantage by reducing costs and improving decision making procedures;

- Models provide a useful rationale for organizing data to support tactical and strategic decision making that is independent of explicit model use.

The paper begins with reviews and critiques of the value chain and the integrated logistics management concept. We discuss the value chain first because it is a more explicit and comprehensive formalism for integrated planning. The paper continues with a case study in a company where senior management was seeking a decision support tool based on models to evaluate a major re-design of their value chain. Then, we present the reasons we believe mathematical programming can and will contribute much more to real-world integrated planning than it has in the past. After that, we discuss the role to be played by powerful new workstations in bringing models to bear on a wide range of important applications. Our presentation in this section centers on the Strategic Logistics Integrative Modeling System (SLIM™), a system designed and implemented for the new workstation platforms (J. F. Shapiro Associates, Inc. [1990]). Experience with a related system that was custom built for the Turkish petroleum industry is discussed in Buchanan et al [1990].

The paper continues with a discussion of SLIM's application to the case study presented earlier. After that, we provide a brief discussion of the similarities and differences between strategic and tactical planning. The importance of "what if" and scenario analyses is then discussed. We continue with a presentation of the benefits of employing advanced decision support systems based on mathematical programming models. The paper concludes with remarks about future directions of information and decision support technologies for integrated planning.

The Value Chain

In his widely read book Competitive Advantage, Porter [1985] espouses the concept of the value chain, which he describes on p. 36,

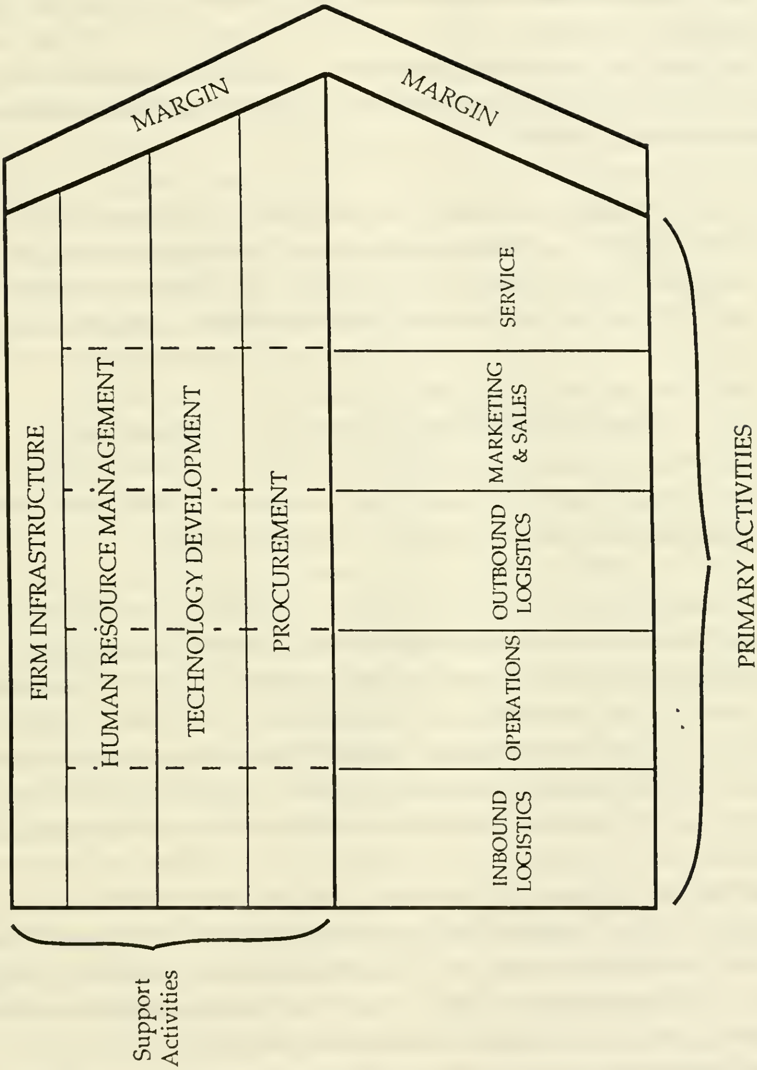
> "Every firm is a collection of activities that are performed to design, produce, market, deliver, and support its product.... A firm's value chain and the way it performs individual activities are a reflection of its history, its strategy, its approach to implementing its strategy, and the underlying economics of the activities themselves."

According to Porter, the value chain consists of nine activity types as shown in Figure 1. Margin, or net revenue, is the difference between gross revenue and total cost, which is comprised of the costs associated with individual activities. Controlling these costs, and adding value to individual activities, is crucial to achieving and maintaining competitive advantage as reflected by the firm's short and long term profit margins.

Porter emphasizes the importance of focusing on the linkages between and among the activities in the value chain. On p. 48, he states

> "Linkages can lead to competitive advantage in two ways: optimization and coordination. Linkages often reflect tradeoffs among activities to achieve the same overall result. ... A firm must optimize such linkages reflecting its strategy in order to achieve competitive advantage. ...The ability to coordinate linkages often reduces costs or enhances differentiation. ...Linkages imply that a firm's cost or differentiation is not merely the result of efforts to reduce cost or improve performance in each value activity individually."

Although Porter employs the term "optimize" here and many other times in the book, nowhere does he indicate that models might be employed to advantage in analyzing the linkages of a firm's value change. Thus, he fails to suggest that the firm pursue



The Generic Value Chain
Figure 1

Source: M. E. Porter, Competitive Advantage, Free Press-MacMillan, 1985.

informational and decision support developments that we believe are the logical next steps, after qualitative analysis, to optimizing linkages.

A firm may achieve competitive advantage by means of lower costs or product differentiation. Porter correctly points out on pages 62 and 63 that

> "(Many companies lack a)...systematic framework for cost analysis...Cost studies tend to concentrate on manufacturing costs and overlook the impact of other activities ...on relative cost position. Moreover, the cost of individual activities is analyzed sequentially, without recognizing the linkages that can affect cost...Cost analyses also tend to rely heavily on existing accounting systems (which) may obscure the underlying activities a firm performs...The value chain provides the basic tool for cost analysis."

These observations about the need to cleanse, transform and organize cost data are similar to ones often heard from operations research practitioners engaged in building models.

Models are obviously appropriate for analyses aimed at identifying and establishing competitive advantage based on cost. Competitive advantage based on product differentiation can also be analyzed by models. Models can determine strategies for coordinating differentiating activities arising in several places in the value chain; for example, integrated production, inventory, and transportation plans that achieve a superior level of order completion and on-time deliveries. Moreover, models can assist in determining if the cost of differentiation is justified by the increased revenues that might result.

The above discussion is not intended to suggest that qualitative business judgment is less essential to strategy formation than it has been in the past. Rather, we would argue that recent developments in information technologies have made it possible to seamlessly merge qualitative and quantitative analysis of a company's strategy. Due to advances in information systems, senior management can base their strategic planning exercises on historical data, data projections, and integrated planning appraisals. Moreover, models can significantly refine management intuition about strategic alternatives, especially by evaluating multiple scenarios of the future. In some instances, the results from integrated planning models will identify initial gaps in management's thinking about strategy. In short, the use of quantitative tools can significantly refine and expand management's qualitative thinking about strategy.

The Integrated Logistics Management Concept

The integrated logistics management concept popular among logistics planning practitioners bears a close similarity to the value chain. According to Stock and Lambert [1987; p.39],

> "The foundation of the integrated logistics management concept is total cost analysis, which we have defined as minimizing the total cost of transportation, warehousing, inventory, order processing, and information systems, and lot quantity cost, while achieving a desired customer service level."

The lot quantity cost in this statement is a proxy for the more general class of avoidable manufacturing costs. Note that Stock and Lambert have properly included the increased cost of information processing required to achieve integration.

The basic tenet of the integrated logistics management concept is that managers should strive to minimize total costs, rather than to myopically control costs over a narrow range of activities. Of course, "total" is a relative notion in the context of managerial decision making. A better way to express the concept is to state that managers should strive to minimize costs, or maximize net revenues, more globally than they have in the past. The extent of global analysis and control depends on the particular circumstances of the company's operations, its competition, and currently perceived management bottlenecks and problems.

The power of the integrated logistics management concept is also championed in the paper by Rose and Sharman [1989]. In their opening paragraph on p. 29, they state

> "In the past few years a growing number of manufacturers have discovered a new source of competitive advantage. They have learned how to improve customer service, slash the cost of materials handling, storage and control, and release cash tied up in inventory and other assets - often all at the same time, and usually without significant new capital investment. The key to all these benefits is nothing more mysterious than a new, integrated approach to the management of logistics, by which we mean the totality of materials flows throughout a company's business system from suppliers to customers."

They go on to state that "(recent) advances in information technology (IT) have opened up exciting opportunities to capitalize still further on the power of integrated logistics."

The similarity of the integrated logistics management concept to the value chain is obvious, but it is less comprehensive as a formalism for viewing the totality of a firm's activities. This is because, until recently, logistics practitioners have been responsible primarily for only two of the nine activities in the value chain; namely, inbound logistics and outbound logistics. The importance of the emerging position of materials manager in many companies reflects a recognition that more global control of activities in the value chain is necessary to improve competitive position.

The resemblance of the related planning philosophies introduce expositional ambiguities with the potential to cause confusion in our subsequent discussions of models and decision support systems. To rectify this situation, we will henceforth treat the terms "optimizing the value chain" and "integrated planning" as synonyms. Moreover, "logistics" is interpreted as the totality of company functions concerned with achieving effective levels of integration.

Illustrative Integrated Planning Case Study

A consumer products company with annual sales of $400 million recently acquired another company making very similar products. Senior management was concerned with means for combining and consolidating the value chains of the two companies. Together they had 10 plants, 32 distribution centers (public warehouses), and 18 distinct product lines. Capital equipment valued in the range of $200,000 to $1,000,000 per unit is used to manufacture the products. The 10 plants contained 64 units, many of which were capable of producing multiple products. Raw material was plentiful and could be obtained locally at each of the plants for approximately the same price.

Response time to customers ranged from 2 to 5 days for stock items. The distribution centers were used to help provide this service level and to satisfy customer requests for local stock availability. All large orders and many small orders (shipped LTL and truckload-crossdock) were shipped directly from plants to the customers; only about 25% of the total weight of deliveries was shipped from the distribution centers.

Senior management appointed a study team to identify the key issues surrounding the consolidation. These were the following:

- o Which plants should remain in operation, and how many operating plants in total are required?

Senior management was sensitive to the impact of transportation costs, which was their second largest cost element. Producing close to the markets would keep these costs down. However, some plants were owned, whereas others were leased, thereby complicating shutdown decisions. Different shutdown costs, or gains in some cases as the result of sales, were associated with each plant. Further, the fixed costs of operating each plant were different due to differences in plant size, property taxes, and lease costs. Variable labor and utility costs differed significantly among the different locations.

- o How should equipment be deployed among plants, and how should equipment at each plant be utilized?

The 64 units of capital equipment among the 10 plants included older, less efficient units as well as newer, more efficient units. For the most part, any unit could be moved to a new plant if it was desirable to do so from a strategic viewpoint. The main constraints on equipment re-deployment were floorspace capacities at the plants. These constraints were not fixed, however, since plant expansion options, with their associated investment costs, were also being considered. Given a deployment of the equipment, decisions regarding their operations remained to be analyzed.

- o What products should be produced at each plant, and what markets should each plant serve?

This issue clearly is interrelated with the previous ones. Many plants with their initial equipment configurations could not produce all products, and in many instances had to receive products from another plant for shipments of multi-product orders to customers. Similarly, distribution centers typically received shipments from multiple plants. Strategic plans needed to take into account projected market demands by product type over the next three years, and by production costs and capacities at each location. Senior management also sought a decision support system for allocating monthly demand to plants in order to fine tune the strategic plans.

o What is the impact of extending shift schedules at the plants?

Three plants operated on a seven day, three shift work schedule. The remaining seven plants operated on a five day, three shift schedule. By increasing the operating schedule to seven days, three shifts per day, at all plants, the company would gain available capacity for their high productivity equipment. Moreover, increased total system capacity would potentially allow the closing down of selected plants, assuming the economics to do so were favorable. Since this change in shift scheduling represented a major cultural change for the company's workforce, management sought to make a clear assessment of the potential operational and cost impacts of the change.

o What are effective guidelines for fulfilling an order in a particular market?

Given effective solutions to the first four sets of questions, guidelines were sought for selecting which of a number of modes to ship an order. These included: truckload or truckload-stopoff from a plant; LTL shipments from a plant or a distribution center; or truckload-crossdock from a plant through a distribution center (or crossdock service). The goal of this analysis was to determine the best origin and mode of shipment for each size category of order to each market.

This completes our discussion of the integrated planning concerns of senior management in the consumer products company, and their motivation in seeking to apply models to analyze these concerns. In this case, many, but not all, of the company's value chain activities were explicitly included in their strategic considerations. Of course, changes in selected parts of the value chain will, in general, have an impact on other parts of the value chain that are initially disregarded. In a later section, we discuss how a data management and modeling system was used to analyze the company's value chain and the results we obtained.

Integrative Planning and Mathematical Programming Models

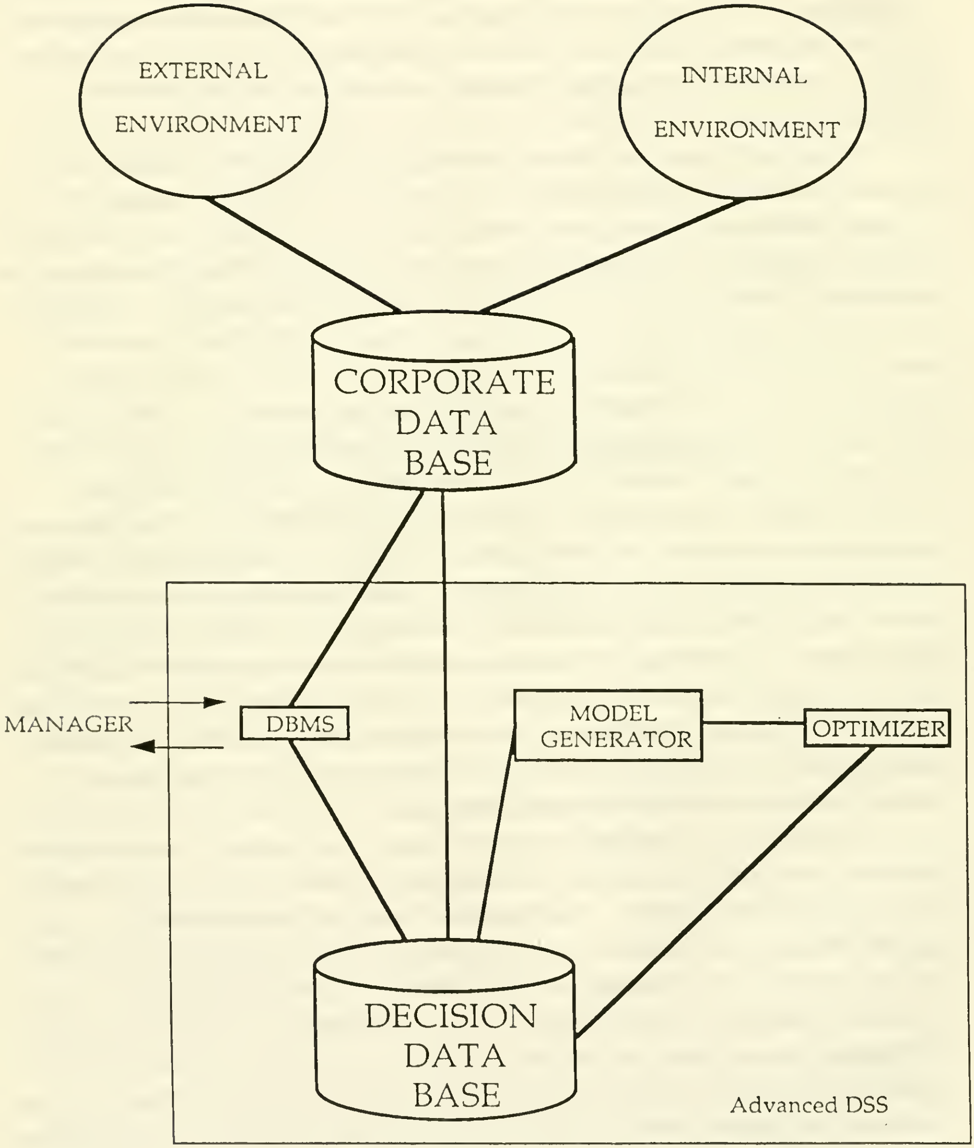
Mathematical programming has been around for a long time. It was one of the disciplines that sprung to life at the start of the information revolution in the middle 1940's; Dantzig [1963; Chapter 2] provides a historical account of its early days. Although many successful applications of mathematical programming have been developed since that time, the field has not yet had the impact that its proponents have advocated.

For several reasons, we believe the time is ripe for a much more pervasive range of successful applications of mathematical programming. First, the formalism can provide the analytic power needed to evaluate complex integrated planning problems, such as those discussed in the previous section. Among the types of mathematical programming models, we have found that linear and mixed integer programming models are capable of describing the vast majority of integrated planning phenomena, at least to a good first approximation. Mixed integer programming extends the resource allocation capabilities of linear programming to capture non-linear costs and resource allocations, and to allow non-numeric conditions to be imposed on a strategy. Non-linearities include fixed costs and economies of scale. Non-numeric conditions are often policy restrictions that may not be justified strictly by the economics of the integrated logistics planning problem being evaluated. For example, a company policy that a critical raw material must be supplied by at least two vendors.

Henceforth, we shall refer to planning software based on mathematical programming models as advanced decision support system (ADSS's). This is to distinguish them from other decision support systems which may not rely on any particular formalism in executing numerical calculations to analyze decisions. Indeed, the lack of formalism has been one of the criticisms leveled at decision support systems (for example, see Sprague and Watson [1989; p. 2]). By contrast, we believe mathematical programming provides a rich and robust formalism on which to base decisions support systems, especially for integrated planning problems.

A second reason for a wider use of mathematical programming models is that they provide a rationalization of the way in which data can and should be organized for decision making. As noted above, this is a major concern of managers now that corporate data bases consisting of transactional data are widely available. When managers express an interest in models, even when they have little knowledge about them, the managers are implicitly seeking higher level perspectives on their transactional data bases in order to make more informed decisions.

The schema in Figure 2 illustrates this point. Note first that we have distinguished between the corporate data base and the decision data base. For a given integrated planning application, the structure and content of the decision data base is the result of a design process aimed at identifying the integrated planning problems to be evaluated, and the models for analyzing them. The structure of the decision data base is determined by the requirements of the model generator that creates the appropriate models for the given family of integrated planning problems.



Advanced Decision Support System Schema

Figure 2

Thus, at the design stage of an ADSS project, the model generator defines the decision data base. By contrast, at run time, model generation is data driven. By this we mean that the model generator creates model structures only for those aspects of the specific integrated planning problem for which data has been provided. For example, if data for a specific instance of the problem ignores sourcing of raw materials, although other instances do consider sourcing, the model generator will not create any equations or decision variables relating to sourcing.

The data in the decision data base differs in several ways from the data in the corporate data base from which they are derived. One important way is that product and customer data will be aggregated for global analysis. The form and extent of the aggregations will depend on the nature of the application. In one application concerned exclusively with distribution, we aggregated according to LTL (less-than-truckload) weight classes. In another application where the allocation of production capacities played a major role, we aggregated products according to similar manufacturing characteristics. Markets are usually aggregated on a geographical basis. A hybrid approach that we have found useful is to distinguish the 50 (say) largest customers as separate demand points, and aggregate the remaining customers on a geographical basis. To facilitate the definition and construction of market zones, an ADSS should provide facilities for producing graphical demand density maps and reports from shipment transaction files. In most instances, the decision data base will consider no more than 20 product families and no more than 200 market zones.

The files in a decision data bases are valuable in their own right, even when they are not used in model generation. Aggregating products into product families provides manufacturing and distribution managers with summarized data that are useful for analyzing short-term capacity loading or transportation decisions. Aggregating customers into market zones can be useful for sales forecasting purposes, and for deciding how to allocate sales efforts to geographical regions.

Aggregations are essential to the construction and optimization of effective models. It is not possible, necessary, or desirable to perform integrated planning analyses at the level of transactional detail that exists in the corporate data base. Sometimes when reporting results, however, it may be worthwhile to disaggregate results. For example, a solution processor might be implemented which employs rules-of-thumb to develop detailed shipment schedules to specific customers based on optimal aggregate flows of products from warehouses to customer zones that were computed using a model.

Clearly, the decision data base will contain a dynamically changing collection of data files created by analysts using the ADSS. The ADSS should therefore contain decision data base management routines that assist the analyst in converting corporate data to their decision oriented forms, and in organizing and maintaining the integrity of decision data files that are employed on a repetitive basis.

A third reason for the wider use of models for integrated planning is the important role that they can play in budgeting and control. Optimization results can provide standards and help set budgets which reflect a global allocation of resources to the full range of activities involved in integrated planning. In addition, budget adjustments due to changing conditions can be rationalized by model re-optimizations. Modern texts on accounting and control make these points in describing how cost-volume-profit analyses can best be carried out using linear and mixed integer programming models (for example, see Kaplan [1982]). In this regard, it is interesting to note that the latest release of a leading spreadsheet package includes a built-in optimization feature (O'Malley [1990]).

The fourth and final reason for the wider use of models is the rapid advance of hardware and software technologies that have made it possible for the manager to acquire, manage and analyze data for integrated planning on a desktop workstation. This is the topic of the following section.

Desktop Workstations for Integrated Planning

The introduction of the personal computer in the early 1980's provided the manager with a self-contained environment in which he/she could acquire and review data, and perform decision support analyses. Since their introduction, great strides have been made in computing and communications hardware and software, allowing data to be easily acquired and disseminated among managers with personal computers on their desktops. These developments are proceeding at a rapid pace.

For ADSS's, the critical breakthrough occurred with the appearance of desktop computers containing the Intel 80386 microprocessor. Coupled with new operating systems, these platforms allow analysts to access the large core memories required to generate and optimize linear and mixed integer programming models of a size required by important applications. Large core memories are also necessary to efficiently manage, organize and edit the large data bases that feed the model generators. In addition, the speed with which the new platforms can perform numerical calculations has made it reasonable to optimize large models locally on the desktop, rather than to ship them off to a mainframe.

Another important feature of the desktop workstation computing environment is the flexibility of available software. ADSS's can be designed and implemented by combining the best of data base management, graphics, and spreadsheet software with model generators and optimizers. Moreover, unlike ADSS's developed for mainframes, which tended to be highly customized for each application in a company, the desktop systems provide a broad range of off-the-shelf capabilities that eliminate, or at least greatly reduce, the need for customization. We discuss one such system to illustrate the state of current developments.

The Strategic Logistics Integrative Modeling System (SLIM™) (J. F. Shapiro Associates, Inc. [1990]) runs on personal computers with an Intel 80386 or 80486 microprocessor, such as the IBM PS/2 Model 70. For 80386 based systems, either an Intel 80387 or a Weitek 3167 math co-processor is required to perform the numerical calculations.

SLIM is an off-the-shelf package for integrated planning that can address a wide range of business situations without customization. These are planning problems spanning sourcing, manufacturing, converting/assembly, distribution, and product pricing activities. Costs, revenues, transformation recipes, resource constraints, transportation flows, and facility location decisions may be modeled in detail using linear and mixed integer programming constructions. Further, models can be specified across multiple time periods allowing, for example, determination of the optimal period to shutdown or open a facility, or analysis of an optimal plan for stockpiling inventories for peak season sales.

The SLIM interface was constructed from a hierarchical database design using a fourth generation database management package. This package also supports data manipulation and editing. Data can be downloaded and uploaded from spreadsheets or corporate databases. It also includes graphical mapping software that allows the generation of demand density and service area maps developed from input and output (optimization results) data.

SLIM incorporates an "Expert Advisor" system that utilizes information on the scope of a model to configure data input menus, screens, and data completeness logic. The hierarchical database is employed to eliminate redundant entry and storage of data, and to provide rapid reporting, automatic data consistency checking, and on-line modification of model data. Standardized routines for aggregating and projecting data are also available. In summary, SLIM is an example of a "workstation environment" in which an analyst can move easily among routines for data collection, data aggregation and analysis, model formulation, model optimization, and post optimality analysis.

The importance of the workstation environment in promoting the development and use of ADSS's for integrated planning cannot, in our opinion, be overemphasized. Given an appropriate level of training, and assuming the necessary data are available and accessible, we have found that an analyst working on his/her desktop computer can develop a decision data base, validate the requisite models, and thoroughly evaluate an integrated planning situation in a remarkably short period of time, when compared to a similar exercise on a mainframe computer. Mainframe computing is too often characterized by distractions and delays, especially if large core memories are required to optimize mixed integer programming models, and mainframe software for data management and graphics is too often inflexible and difficult to learn how to use.

Case Study Analysis

It is instructive to discuss how SLIM was applied to the integrated planning questions faced by the consumers products company that were discussed in the case study. The first step in preparing the decision data base was to define aggregate of products and markets. We aggregated the 1,500 items sold by the company into 18 product groups based on manufacturing resource requirements and major customer segments. This choice was dictated in part by the major strategic planning issues to be addressed.

Working with the company's sales manager, we used SLIM's geographic mapping software to display demand concentrations by 3 digit zipcode areas, and thereby identified 81 market areas throughout the U.S. Approximately 98% of total demand was found to lie within a 25 mile radius of these 81 points. Transportation costs were based on the truckload rate to serve these markets, as determined by shipments to the city with the greatest demand in the market area. These 81 market areas were then matched to individual salesmen projections for each major customer segment served. The company's sales forecasts for each product group - pessimistic, middle-of-the-road, and optimistic - were assembled in a bottom-up manner from these projections.

The next step in developing the decision data base was to define the cost and capacity parameters for the production and transportation activities. Working with operations personnel, we defined production recipes for each product (family) for each of several units of equipment, and the required hours and cost per hour to produce one ton of product for each equipment unit. We also determined fixed and variable costs for each plant, and capacities for each unit of equipment, and for each plant in total. This production information relating to equipment was based on an aggregation of the 64 units of equipment into 18 types of capacity resource. Since a major purpose of the study was to evaluate the deployment of equipment to plants, the model permitted certain portions of each of the 18 types of capacity to be re-assigned (re-allocated) to plants that would realize the greatest benefit.

A single period snapshot model was then implemented and validated using data from a recent three month period. Production activities and transportation flows were constrained to levels actually incurred during that period, and the cost results from the model were compared with actual costs. We fine tuned the cost data and re-ran the model to provide a base against which potential cost improvements could be measured.

The model was then allowed to optimize company-wide production and distribution operations without the option of moving equipment to new plants, and without policy constraints. Analysis of the results revealed that some policy constraints were required to make the model more realistic. For example, several older and slower equipment units were completed unused, although these units could be employed to make specialty products, thereby allowing newer equipment to produce larger lot sizes of standard products. This situation was modeled by assigning minimal production volumes to the older machines. Once the necessary policy constraints had been identified and added to the model, we re-optimized it using demand projections for the next fiscal year. This run gave the base solution for operating the company without moving equipment to new plants, and without other options of interest to senior management including the construction of new plants, the closure of existing plants, the addition of overtime shifts at certain plants, and changes in order completion policies.

We added these tactical and strategic options to the model and optimized it under a variety of scenarios. After approximately 30 model runs, SLIM had identified a realistic strategy that could reduce controllable costs by 15% on an annual base of approximately $50M. The strategy involved the closure of four plants and significant shifting of equipment among plants so as to reduce transportation costs and exploit variations in labor costs. In the final analysis, senior management chose to implement a different strategy, one that reduced controllable costs by only 8%, because they chose not to close certain facilities which the model indicated should be closed for purely economic reasons. Non-economic reasons that influenced their thinking included the maintenance of company moral, the wish to avoid excessive operational disruption, and the need to maintain a strong company image with respect to customers and competitors.

We re-optimized the model based on these management judgments to determine key, but limited equipment relocations. The final configuration of plants and equipment provided a basis for determining company-wide production plans and assignment of markets to plants. In particular, we expanded the product groups considered by the model from 18 to 35, thereby allowing aggregate production scheduling details to be evaluated. The additional detail was also useful in providing guidelines for inter-plant shipments required to support the company goal of single source shipping of most products to each market.

We then used plant-market assignments defined by the model as inputs to a simulation model for determining order distribution guidelines. Thus, although the optimization model could have included modal shipping choices for products flows through the distribution centers to the markets, this level of detail turned out to be unnecessary. The simulation showed clearly that truckload-crossdock shipping was the most effective way to serve most markets, and this mode was assumed in the optimization model.

At the moment, the company is designing procedures to incorporate the distribution guidelines in the their order entry system, which in turn will drive their production schedule. The guidelines will be updated according to strategies determined by SLIM each time equipment is relocated, or a plant is closed. In the future, on a regular basis, the firm plans to compare actual operating results against optimized results in which production capacities and recipes are held fixed at their actual values, but market demands are optimally allocated to plants. If the actual and optimal product flows from plants to the markets are not close, this will be a signal that additional system wide analysis using SLIM is required.

In summary, the extensive quantitative analysis of the company's operating structure and policies provided by SLIM allowed senior management to formulate strategies that significantly reduced the costs of meeting forecasted demand, but at the same time, held organizational disruption to an acceptable level. Guidelines for efficient production and distribution practices identified by SLIM will be incorporated in the company's operations to sustain the level of cost savings identified by the more strategic analyses.

As in this case study, we have found that SLIM is most effective when applied in an inductive or problem solving mode. By this we mean that models should be constructed, and data collected and organized, for focussed and pressing management problems. This is in contrast to a deductive approach in which a study team sets out to build a complete model of the company which they hope will be used to evaluate any integrated planning problems that might arise. The latter approach is, in our opinion, doomed because the model will fail to respond adequately to specific analytic needs. Moreover, such an exercise is extremely difficult to bring to closure.

Strategic versus Tactical Planning

We wish to comment briefly on the distinction between strategic and tactical logistics planning problems. At the risk of over-simplification, strategic planning is concerned primarily with acquiring resources over the longer term, whereas tactical planning is concerned with utilizing these resources over the shorter term. As we noted above, however, evaluation of new resources requires an understanding of how they would be utilized in conjunction with existing resources. Thus, the distinction between strategic and tactical planning is often blurred. In many instances, it becomes a question of the degree to which a company has options for changing its available resources.

An ADSS such as SLIM can be applied to a very wide class of strategic and tactical logistics planning problems ranging from the evaluation of a major acquisition down to production and distribution planning by weeks for the next four weeks. For example, in one company, SLIM was validated by the generation and optimization of a four period (quarterly) tactical model of the company's operations for a previous year. The validated model and its decision data base were then extended to evaluate the strategic impact on net revenues of a plant acquisition for selected years in the future.

SLIM is not appropriate for very detailed operational scheduling problems, such as vehicle routing or job-shop scheduling. These problems are characterized by a large number of time periods and by great detail depicting costs and feasible operating patterns. Moreover, operational planning systems for such applications tend to be much more highly customized to a firm's operations.

What If and Scenario Analysis

"What if" and scenario analysis refer to iterative model generation and optimization aimed at evaluating the impact of uncertainties on integrated planning. If there is a distinction to be made between the two terms, we would say that what if analysis involves ad hoc adjustment of key parameters, whereas scenario analysis involves a more formal process of adjusting comprehensive sets of parameters characterizing future scenarios. Again without mentioning models, Porter [1985] advocates the use of scenarios as a planning tool. On p. 446, he writes

> "As the perceived need to address uncertainty explicitly in planning has grown, a few firms have begun to use scenarios as tools to understand the strategic implications of uncertainty more fully. A scenario is an internally consistent view of what the future might turn out to be. By constructing multiple scenarios, a firm can systematically explore the possible consequences of uncertainty for its choice of strategies."

The need to perform scenario analyses implies ADSS's must be sufficiently flexible to allow easy specification of the data describing scenarios. In SLIM, for example, we incorporated automatic procedures for escalating demand and cost data. These might be escalations of global demand data and cost data files, or user specified data subsets. An example of the latter type of scenario specification is: Escalate demand in Northeast markets by 10%, and escalate demand in West Coast markets by 15%. Such a scenario would be specified by first indicating the 3-digit zipcodes defining the Northeast and West Coast markets, and then using SLIM's data management package to perform the indicated escalations.

Management's desire to perform scenario analysis suggests that the time may be near when practitioners will, for carefully selected applications, extend deterministic mathematical programming models for integrated planning to stochastic programming with recourse models. An excellent introduction to such models is given in Wagner [1969]. A stochastic programming with recourse model considers multiple scenarios of an uncertain future, simultaneously determining optimal contingency plans for each scenario and a here-and-now strategy that optimally hedges against these plans. (See, for example, Bienstock and Shapiro [1988] who applied stochastic programming with recourse to a class of integrated planning problems faced by electric utilities.)

Although stochastic programming with recourse models have considerable appeal for certain applications, they can easily attain a size that makes them impractical. The explosion of model size, also known as the "the curse of dimensionality", may appear inescapable once the practitioner decides to explicitly model an uncertain future with respect to several planning dimensions, such as market demand, raw material availabilities and costs, or the characteristics of a new manufacturing technology. To avoid further digression, we simply state our belief that the difficulties of problem size need not be insuperable, and that the stochastic programming with recourse modeling paradigm, when judiciously applied, has significant potential for future application.

Benefits of Advanced Decision Support Systems

The potential benefits of using an ADSS fall into five categories

- o Explicit reduction in costs or increase in profits;
- o Implicit reduction in costs or increase in profits by more rational, systematic planning;
- o Improvement in communication;
- o Clarification of organizational goals, decision options, constraints;
- o Provide focus for data collection and interpretation.

Of course, the primary benefit is the explicit reduction in costs or increase in profits, although for strategic analyses of an exploratory nature, there may be no way to measure such direct benefits. Since the most compelling argument for convincing senior management to test and adopt an ADSS is its potential contribution to the bottom line on the company's P & L statement, we discuss briefly another concrete example where such a system produced a significant result.

Recently, we implemented a warehouse location model for a distribution company. The model was comprised of costs, activities and constraints describing product sourcing, in-bound transportation, warehouse operations, out-bound transportation, and inventory management. At the start of the study, the company had 6 warehouses located throughout the U.S., and the materials manager in charge of the study wished to consider 17 potential new locations. Under a range of demand scenarios, the model indicated that the company could reduce projected total costs by approximately 10% by shutting down 3 existing warehouses, and opening 6 smaller ones located closer to their major markets.

The level of cost reduction was not entirely unexpected, but the materials manager needed the detailed and extensive analyses provided by the model to convince senior management to implement major changes in the company's value chain.

In general, it has been our experience that analysis of integrated planning problems based on mathematical programming models determine strategies that are 3% to 20% lower in cost. Many companies are reluctant, however, to publicize their positive experiences with ADSS's because they feel the systems give them a competitive advantage.

Implicit benefits can also be very significant. Several years ago, we developed an annual planning model for a personal products company. The model encompassed sourcing, contract filling and distribution strategies to regional warehouses of an entire product line. The product was about to undergo a major change that would alter the balance between filling and transportation costs.

The company's manufacturing VP had previously been using five contract filling sites, very much against the wishes of the product line's marketing manager who felt that fewer sites would be less costly. Model optimization under a range of demand scenarios clearly demonstrated that two of the five contract fillers could be eliminated with a significant total cost savings. Faced with such analysis over the course of several months, the manufacturing VP capitulated and terminated the company's contracts with the two uneconomical sites. At the end of the first year following the product change, profits had doubled, an improvement that the marketing manager attributed in large part to better planning practices that were stimulated by extensive use of a model.

Future Directions

In this paper, we have argued that the outlook for applying advanced decision support systems (ADSS's) to integrated planning is bright. We conclude with a brief discussion of likely future developments as ADSS's for integrated planning find wider use, and as information technologies continue to improve.

We expect new applications to emerge reflecting senior management's enhanced awareness of the scope and potential benefits of integrated planning. One important new application is in optimizing financial flows for multi-national corporations (Klimczak, Magee and Shapiro [1990]). Models for this class of problems must capture decisions and constraints regarding taxes and financial flows among its subsidiaries, and link these decisions to traditional logistics decisions regarding sourcing, manufacturing, and distribution. Another important new application area is in integrating logistics models describing the efficient supply of products to the markets with quantitative marketing models describing how advertising, promotions, pricing and service factors create and sustain market demand (Covert [1987]). More generally, we expect to see extensions of current integrated planning models, which focus on cost competition and customer service only as it relates to delivery lead time, to models that explicitly incorporate decisions and constraints relating to other aspects of customer service, and to quality and product differentiation.

We are in the midst of another rapid surge in the capabilities of computer and communications technologies. In hardware, we have seen a dramatic improvement in the performance of microprocessors for desktop workstations. Starting at a level of 1 MIP (million instructions per second) in 1985, the processing speed of commercially available microprocessors has risen to a current level of 40 MIPS. Performance is expected to significantly exceed 100 MIPS by 1993, and may reach as high as 1000 MIPS by 1995. This phenomenon has been called "The attack of the killer micros," (Howe [1990]).

ADSS's such as SLIM will undoubtedly continue to evolve to exploit these improvements in hardware. To a certain extent, the future has already arrived. A major computer manufacture is now selling a desktop workstation that can perform large scale optimizations at about half the speed of their mainframe computer; the workstation sells for less than 5% of the selling price of the mainframe.

Perhaps equally important as hardware advances are the changes taking place in technical computing environments. Emerging computing architectures for cooperative processing are highly suited to integrated planning. These architectures provide individual workstation users with flexible and efficient access to common, corporate data bases, and to high speed computing facilities. By streamlining acquisition of data pertaining to diverse company functions, the new architectures will facilitate the development and use of integrated planning tools.

Of course, SLIM and similar systems for integrated planning have proven highly effective using today's workstation technology. The barrier to better integrated planning is not technology, but people. Individuals and organizations need to understand the capabilities of new ADSS's, and adapt their business procedures to exploit the insights they provide. At the same time, individuals and organizations must learn to appreciate that models are not intended to replace human and managerial judgment. Instead, they are intended to expand the manager's intuition about and analysis of integrated planning problems to help him/her identify more competitive strategies.

But even with dramatic improvements in technology, there can be "no gain without pain." To model a large or complex portion of a company's value chain, an analyst may need to spend a solid month, or longer, in acquiring, organizing and preparing data for model validation. Moreover, the effective use of an ADSS for integrated planning involves considerable art as well as science. This means that an analyst without previous experience will require more than the usual amount of training.

Organizational barriers to improved integrated planning stem in part from the failure of some companies to adapt their organizational structure to exploit information and analysis. In these companies, decisions are still made in a de-centralized and uncoordinated manner similar to the way they were made before the advent of corporate data bases. Job definitions and incentive schemes for middle managers need to be changed to more strongly encourage them to seek and implement strategies that cut across traditional functional boundaries.

An interesting and potentially important area of research is to reconcile the practice of integrated planning based on data driven mathematical programming models with the economic theory of the firm. Holmstrom and Tirole [1987] provide an extensive review of the central themes of this theory, which is concerned with issues that are highly relevant to our discussion here. For example, Holmstrom and Tirole discuss research into the limits of integration where, as they say on p. 5,

> "What is the purpose of the firm and what determines their scale and scope? These are two basic questions that a theory of the firm must address. Yet, satisfactory answers have proved very difficult to come by. The challenge is to offer a genuine trade-off between the benefits and costs of integration. "

They also discuss issues surrounding the internal organization of the firm as it relates to the structure of the firm's hierarchy, the rules of decision-making, and the nature of the incentive system within the hierarchy.

We conclude by simply stating our belief that, given the magnitudes of the cost savings we have seen resulting from analyses by ADSS's, management in most companies will very soon recognize the value of acquiring and deploying such systems for a variety of integrated planning purposes. The competitive pressures of today's business environment almost dictate that management commit to using these more powerful tools of analysis.

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