Bottom-up vs. Top-down Approaches
To Supply Chain Management and Modeling

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Abstract

This paper reports on applications of optimization modeling systems to integrated supply chain management. Such systems assist managers in coordinating functional activities across the company's supply chain and in coordinating inter-temporal decisions across operational, tactical and strategic planning horizons. The paper begins with a discussion of the differences between Transactional IT, which is concerned with acquiring, processing and communicating raw data about the company's past and current supply chain operations, and Analytical IT, which is concerned with evaluating decisions over short, medium and long term futures. The paper then examines a Supply Chain Modeling System Hierarchy composed of six optimization modeling systems, which are analytical, that are tightly linked to four information systems, which are transactional. An important component of these optimization modeling systems are supply chain decision databases that are different than, but derived from, transactional databases. Principles for creating and exploiting these decision databases are presented.

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1. Introduction

The term **"supply chain management"** crystallizes concepts about **integrated planning** proposed by operations research practitioners, logistics experts, and strategists over the past 40 years (e.g., Hanssman (1959), LaLonde et al (1970), Porter (1985)). Integrated planning refers to **functional coordination** within the firm, between the firm and its suppliers, and between the firm and its customers. It also refers to **inter-temporal coordination** of supply chain decisions as they relate to the firm's operational, tactical and strategic plans.

Practical developments in supply chain management have grown in the 1990's due to advances in information technology (IT). Astonishing gains in PC computing speed, coupled with improvements in communications and the flexibility of data management software, have promoted a range of applications. **Enterprise Resource Planning** (ERP) systems, which have appeared within the past five years, offer the promise of homogeneous, transactional databases that will enhance integration of supply chain activities. In many companies, however, the scope and flexibility of installed ERP systems have been less than desired or expected (Bowersox et al (1998)).

Still, competitive advantage in supply chain management is gained not simply through faster and cheaper communication of data. As many managers have come to realize, ready access to transactional data does not automatically lead to better decision making. A guiding principle is:

*To effectively apply IT in managing its supply chain, a company must distinguish between the form and function of **Transactional IT** and **Analytical IT***

Transactional IT is concerned with acquiring, processing and communicating raw data about the company's past and current supply chain operations, and with the compilation and dissemination of reports summarizing these data. Typical examples are POS recording systems, general ledger systems, quarterly sales reports, and ERP systems.

By contrast, Analytical IT evaluates supply chain decisions based on models constructed from **supply chain decision databases**, which are largely, but not wholly, derived from the company's transactional databases. Analytical IT is comprised of these supply chain decision databases, plus modeling systems and communication networks linking corporate databases to the decision databases. It is concerned with analyzing decisions over short, medium and long term futures. Typical examples of this type of IT are modeling systems for scheduling weekly production, forecasting demand for next month and allocating it to manufacturing facilities, or locating a new distribution center.

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Differences between Transactional and Analytical IT are discussed further in Shapiro (1998).

As we argue in this paper, **mathematical programming models** are critical elements of Analytical IT. Such models can unravel the complex interactions and ripple effects that make supply chain management difficult and important. They are the only analytical tools capable of fully evaluating large numerical data bases to identify optimal, or demonstrably good, plans. They can also measure tradeoffs among cost or revenues and service, quality and time. Linear and mixed integer programming models are the types most commonly used for supply chain management problems. In practice, mixed integer programming models are best combined with approximation and heuristic methods, especially for scheduling applications.

Managers use the term **optimization** when pursuing IT and business process changes that will improve supply chain management practices. For most managers, however, the term has a vague connotation. They are often unaware of the rigor of mathematical programming methods and their potential to significantly improve the bottom line. Nevertheless, in promoting mathematical programming models, the operations research specialist is better served by referring to them as optimization models. For this reason we will henceforth refer to systems using mathematical programming models as **optimization modeling systems**

Inter-temporal coordination of supply chain decisions has received far less attention than functional coordination. Moreover, current efforts to improve supply chain management using IT and business process re-design have focused on two domains, operations and strategy, with radically different time frames, planning concerns and organizational needs. Companies are seeking to improve **supply chain operations** by acquiring off-the-shelf software systems for manufacturing and distribution planning that are add-ons to ERP. These systems focus largely on scheduling problems in providing myopic evaluations of portions of a company's supply chain. Their analytical capabilities usually do not include mathematical programming models and methods. These systems' capabilities are rarely customized to the peculiarities of the company's operational problems.

At the strategic level, an increasing number of companies are employing optimization modeling systems to study **resource acquisition decisions** that will strongly affect their long-term competitiveness. Such decisions include the location and mission of new facilities, perhaps to support new products, bid prices for mergers and acquisitions, and consolidation of existing facilities under conditions of excess capacity. These optimization modeling systems may be developed in-house, acquired from strategy consultants, or from third-party vendors. They are rarely regarded as permanent tools that the company can and should employ on a repetitive basis to review strategic decisions.

Thus far, little effort has been made to link analytic tools and databases at the two extreme levels of planning. The development of optimization modeling systems for **tactical supply chain management**, which would bridge the gap, has been largely ignored. The goal of a company employing such a system would be to adapt organizational processes to exploit global insights provided by it on a routine basis, say once a month. The potential rewards of doing so are enormous. Limited applications have shown that a company can expect to reduce total supply costs by at least 5% through the use of tactical optimization modeling systems.

The purpose of this chapter is to review conceptual and practical developments in the bottom-up and top-down approaches to integrated supply chain management. Particular attention will be given to the present and future roles of optimization modeling systems in achieving such integration. Related developments in IT and business process re-engineering will also be discussed.

2. Hierarchy of Supply Chain Optimization Modeling Systems

In the previous section, we emphasized the importance of inter-temporal integration of supply chain activities as well as their functional integration. Integration can be most fully achieved by the application of a suite of optimization modeling systems to the gamut of operational, tactical and strategic planning decision problems faced by the company. These Analytical IT systems are linked to overlapping supply chain decision databases created in large part from data provided by Transactional IT systems.
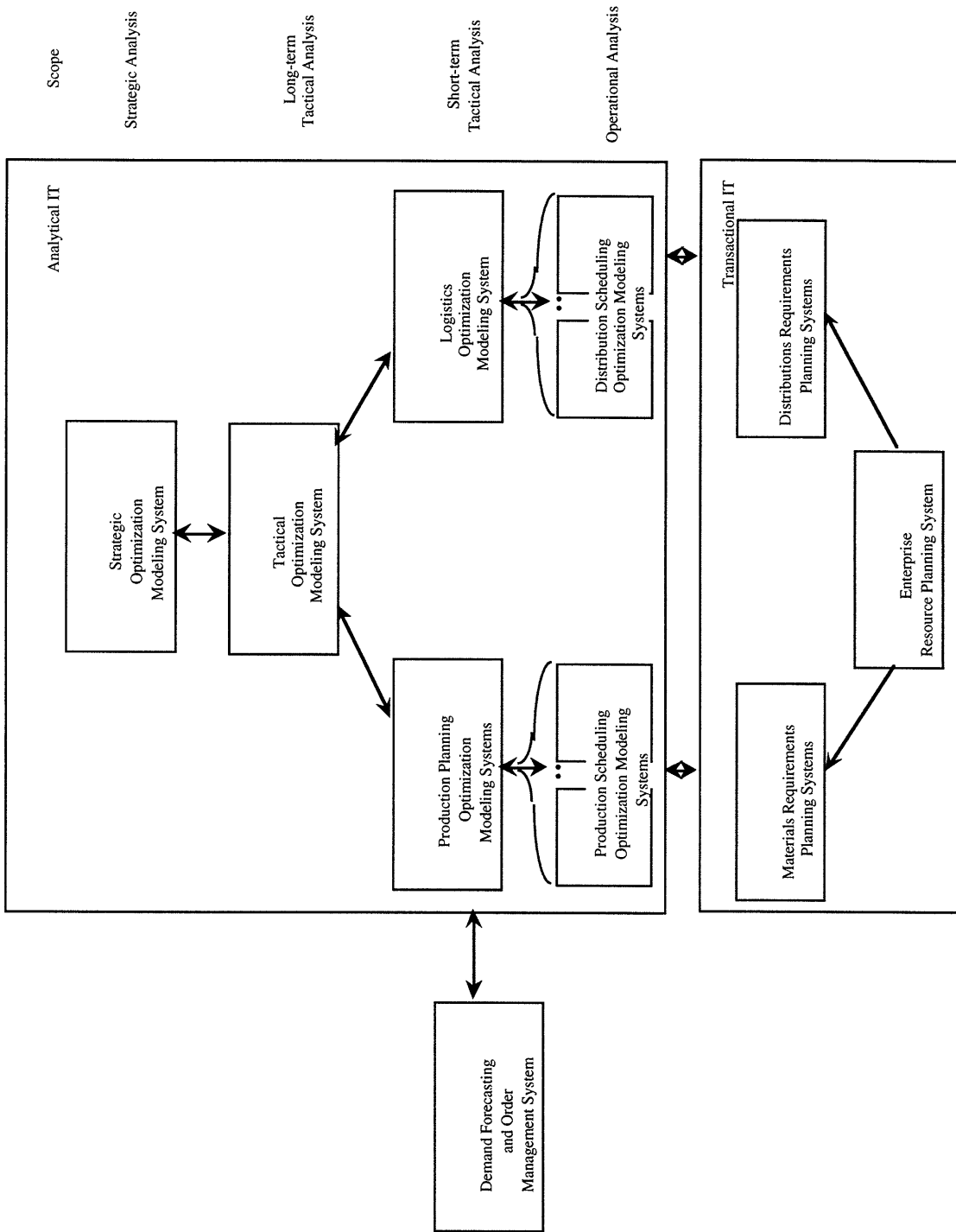
2.1 Components of the Supply Chain System Hierarchy

In Figure 1, we display the Supply Chain System Hierarchy comprised of optimization modeling systems and transactional systems responsible for inter-temporal and functional integration of supply chain activities in a manufacturing and distribution company with multiple plants and distribution centers. As shown in the Figure, the six types of optimization modeling systems are Analytical IT and the four other systems are Transactional IT. Strictly speaking, the Demand Forecasting and Order Management System is a hybrid with analytical capabilities for forecasting demand and transactional capabilities for handling customer orders.

Distinctions among the transactional and scheduling systems displayed in Figure 1 have become blurred. Software companies offering ERP systems have either acquired or entered into alliances with companies offering operational modeling systems. Similarly, some DRP systems include modules for vehicle scheduling and forecasting. For the purposes of discussion, we choose to maintain separation among the form and function of these various component systems.

The transactional and scheduling systems in the System Hierarchy represent the current bottom-up thrust in supply chain management. IT developments are the driving force for innovation, with business process re-design as a natural consequence. The area is red hot with annual sales of software in the hundreds of millions of dollars and growing rapidly (e.g., see Naj(1996)).

Strategic optimization modeling systems in the System Hierarchy reflect the top-down thrust in supply chain management. The driving force is senior management's need for strategic analysis in the face of globalization of the company's markets and supply chains, and competition in cost and service. An increasing number of studies, which employ strategic optimization modeling systems, are being performed by consultants to provide management with insights into the evolution and re-design of their supply chains, and answers to "what if" questions about the long-term future.

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Scope

Strategic Analysis

Long-term
Tactical Analysis

Short-term
Tactical Analysis

Operational Analysis

Analytical IT

Transactional IT

Strategic
Optimization
Modeling System

Tactical
Optimization
Modeling System

Logistics
Optimization
Modeling System

Distribution Scheduling
Optimization Modeling
Systems

Production Planning
Optimization
Modeling Systems

Production Scheduling
Optimization Modeling
Systems

Distributions Requirements
Planning Systems

Enterprise
Resource Planning System

Materials Requirements
Planning Systems

Demand Forecasting
and Order
Management System

Supply Chain Modeling System Hierarchy
Figure 1

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Long-term and short-term tactical supply chain planning, and systems in the System Hierarchy to support them, have thus far been mainly ignored. They are the most difficult areas in which to develop better planning methods, based in part on the use of optimization modeling systems, because they require radical business process re-design. We return to a discussion of this point in the next sub-section where we more explicitly address timing issues associated with exercising the systems in the System Hierarchy.

This Supply Chain System Hierarchy is hypothetical. To the best of our knowledge, no company has implemented and integrated all ten types of systems, although many companies have implemented several of them. As IT for supply chain management continues to improve and modeling applications expand, we expect that companies will in the near future implement versions of the entire System Hierarchy.

Starting from the bottom-up, the following are synopses of the capabilities of each system type.

Enterprise Resource Planning (ERP) System: The ERP System manages the company's transactional data on a continuous, real-time basis. This System standardizes the company's data and information systems for order entry, financial accounting, purchasing, and many other functions, across multiple facilities and business units. Despite the claim implied by the term ERP, effective "resource planning" across the "enterprise" can be identified only by optimization models created by the modeling systems using data from the ERP System. See Bowersox et al (1998) for further discussion of ERP systems and their impact on supply chain management. ∎

Materials Requirement Planning (MRP) System: Analysis with the MRP System begins with a **master production schedule** of finished products needed to meet demand in each period of a given planning horizon. Using these data, along with a **balance on hand** of inventories of raw materials, work-in-process and finished goods, and a **bill of materials** description of the company's product structures, the MRP System develops **net requirements** of raw materials and intermediate products to be manufactured or ordered from vendors to meet demand for finished products. Products at all stages of manufacturing are analyzed by the MRP System at the SKU level. See Baker (1993) and Sipper and Bulfin (1997) for more discussion about MRP systems and the role of optimization models in determining a master production schedule. ∎

Distribution Requirements Planning (DRP) System: Analysis with a DRP System begins with **forecasts** of finished products to be transported, a **balance on hand** of inventories of these products at plants and distribution centers, and **inventory management data** such as safety stock requirements, replenishment quantities, and replenishment times. In conjunction with the Distribution Scheduling Optimization Model Systems, the DRP System then schedules in-bound, inter-facility, and out-bound shipments through the company's logistics network, taking into account a wide range of **transportation factors** such as vehicle loading and routing, consolidations, modal choice, channel selection, and carrier selection. Products throughout the logistics network are analyzed by the DRP System at the SKU level. See Stegner (1994) for more discussion about DRP systems. ∎

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Demand Forecasting and Order Management System: This System combines data about current orders with historical data to produce requirements for finished products to be met by the operational, tactical and strategic plans. For operational and short-term tactical planning, an important challenge is to manage the transition from forecasts, which have a significant degree of uncertainty, to orders, which have much less uncertainty. Longer-term planning requires linkages to data on industry and economic factors that have a high degree of uncertainty. See Makridakas and Wheelwright (1989) or Rosenfield (1994) for further discussions of demand forecasting. ■

Production Scheduling Optimization Modeling Systems: These are modeling systems located at each plant in the company's supply chain that address operational decisions such as the sequencing of orders on a machine, the timing of major and minor changeovers, or the management of work-in-process inventories. The models must fit the environment, which may be discrete parts manufacturing, process manufacturing, job-shop scheduling, or some hybrid. A single facility may require different modeling systems at different stages of manufacturing; for example, fine paper production at a mill involves process manufacturing to produce mother rolls of paper followed by job-shop scheduling to produce the final products. See Shapiro (1993a) for a review of relevant mathematical programming models. Naj (1996) discusses business applications for such systems and the capitalization of firms offering them, including i2, Red Pepper, and Manugistics. ■

Distribution Scheduling Optimization Modeling Systems: The manufacturing and distribution company faces a variety of vehicle and other scheduling and operational planning problems. In addition to local delivery of products to customers, some companies must decide on a short-term basis which distribution center should serve each market based on inventory availability. As with production scheduling, distribution scheduling problems and models vary significantly across industries. See Golden and Assad (1988) for a broad treatment of vehicle routing algorithms and applications, and Hall and Partyka (1997) for a survey of off-the-shelf packages for vehicle routing. ■

Production Planning Optimization Modeling Systems: Each plant in the company's supply chain uses its version of this optimization modeling system to determine a master production plan for the next quarter for each stage of manufacturing, along with resource levels and resource allocations for each stage, that minimize avoidable manufacturing costs. As part of the optimization, the model also determines work-in-process inventories and major machine changeovers. The models used by this System will be multi-period as well as multi-stage. Therefore, for reasons of computational necessity, products are aggregated into product families. These aggregations are reversed when the System hands off the master schedule to the plant's Production Scheduling and MRP Systems. Although many papers have appeared in the academic literature discussing production planning models with this broad scope (e.g., see Thomas and McClain (1993)), few modeling systems based on them have yet been implemented. Exceptions are the systems developed at Harris Corporation (Leachman et al (1996)) and at Sadia (Taube-Netto (1996)). ■

Logistics Optimization Modeling System: This System determines a logistics master plan for the entire supply chain that analyzes how demand for all finished products in all

markets will be met over the next quarter. Specifically, it focuses on the assignment of markets to distribution centers and other facilities responsible for sourcing them. Its goal is to minimize avoidable transportation, handling, warehousing and inventory costs across the entire logistics network of the company. Again, for reasons of computational necessity, finished products are aggregated into product families and markets are aggregated into market zones. These aggregations are reversed when the System hands off the master schedule to the plant's Distribution Scheduling and DRP Systems. This type of optimization modeling system has also not yet been widely implemented. ■

Tactical Optimization Modeling System: This System determines an integrated supply/manufacturing/distribution/inventory plan for the company's entire supply chain over the next 12 months. Its goal may to be minimize total supply chain cost of meeting fixed demand, or to maximize net revenues if product mix is allowed to vary. Raw materials, intermediate products and finished products are aggregated into product families. Similarly, markets are aggregated into market zones. This is another type of optimization modeling system that has not yet been widely implemented. ■

Strategic Optimization Modeling System: This System is used to analyze resource acquisition and other strategic decisions faced by the company such as the construction of a new manufacturing facility, the break-even price for an acquisition, or the design of a supply chain for a new product. Its goal may be to maximize net revenues or return on investment. A number of off-the-shelf packages, with varying degrees of modeling capabilities, are available for this type of application. See the software guide edited by Haverly and Whelan (1996). Examples of strategic studies include Shapiro (1992), Shapiro et al (1993b), Arntzen et al (1998), Barlund et al (1998). ■

In Figure 1, we have shown data being passed in both directions between each optimization modeling system and those that are immediately above and below it in the hierarchy. Clearly, the decision data bases of these systems overlap. Moreover, data directed downward is disaggregated whereas data directed upward is aggregated. See Shapiro (1998) for more details.

For production planning problems, communication among inter-temporal problems and models has been called hierarchical planning (Bitran and Tirupati (1993)). The approach is valid for more general supply chain problems, and to other areas of business planning. Hierarchical planning includes mathematical programming decomposition methods that formalize communication between levels; Graves (1982) provides a good example of this approach. Although such methods may be beyond the reach of most practical implementations, they provide a very useful way of thinking about supply chain problem linkages.

Finally, the System Hierarchy mechanizes the suggestion by Hammer and Champy (1993; p. 93) that IT advances permit "businesses (to) simultaneously reap the benefits of centralization and decentralization." This is a main theme underlying the widespread interest in integrated supply chain management. But, if it is to become more than a vague and ultimately unachieved goal, companies must actively re-engineer their business processes to promote analysis and communication as depicted in Figure 1.

	Planning Horizon	Model Structure	Objective Function	Frequency of Analysis	Cycle Time	Run Time
Strategic Optimization Modeling System	1 - 5 years	Yearly snapshots	maximize net revenues or returns on assets	Once a year	1 - 2 months	1 0 - 60 min
Tactical Optimization Modeling System	12 months	3 months, 3 quarters	minimize total cost of meeting forcasted demand or maximize net revenue by varying product mix	Once a month	1 week	60 - 120 min
Production Planning Optimization Modeling System	13 weeks	4 weeks, 2 months	minimize avoidable production and inventory costs	Once a week	1 day	10 - 30 min
Logistics Optimization Modeling System	13 weeks	4 weeks, 2 months	minimize avoidable logistics costs	Once a week	1 day	10 - 30 min
Production Scheduling Optimization Modeling Systems	7 days to 28 days	7 days to 28 days	minimize myopic production costs	Once a day	30 min	10 min
Distribution Scheduling Optimization Modeling Systems	7 days to 28 days	7 days to 28 days	minimize myopic distribution costs	Once a day	30 min	10 min
MRP Systems	7 days to 28 days	7 days to 28 days	not applicable	Once a week	1 - 3 hours	60 min
DRP System	7 days to 28 days	7 days to 28 days	not applicable	Once a week	1 - 3 hours	60 min
Forecasting and Order Management System	1 week - 5 years	Varied	not applicable	Varied	Varied	10 sec - 10 min
Enterprise Resource Plaining System	not applicable			Real-time or Continuous		not applicable

Features of Analytical and Transactional Systems

Table 1

2.2 Frequency of Analysis, Cycle Times and Run Times of Supply Chain Systems

In the previous sub-section, we did not address details about the intended mode for using components of the System Hierarchy. We remedy this deficiency by discussing several timing features of these systems:

- **frequency of analysis** – the number of times each year, quarter or month that managers and planners use the system
- **cycle time** – how long it takes to complete analysis with the system each time it is used
- **run time** – batch time required for each run of the system

These times are displayed in Table 1. They are representative, rather than definitive, and may vary significantly from company to company, although within limits. The frequency of analysis will be much longer than once a week for the Tactical Supply Chain Modeling System, and much shorter than once a quarter for the Production Scheduling Modeling System.

The planning horizons of the systems overlap, which facilitates coordination and communication among them. Note also that all optimization modeling systems are intended to be exercised on a **rolling planning horizon**; that is, the planning horizon of each model is longer than the frequency of analysis. As we descend in Table 1 from strategic to operational systems, the planning horizon becomes shorter while the description of time in the models, as measured by the number of periods, becomes more detailed.

In addition, the objective function shifts from net revenue maximization to avoidable cost minimization as we move from strategic to operational planning. In principle, net revenue maximization should be sought at all planning levels, but the company may have few options to affect revenue at the operational level. One can expect or hope that, in the coming years, net revenue maximization will work its way down the hierarchy as companies improve their capabilities to exploit modeling systems. For example, the Production Planning Optimization Modeling System could be employed to maximize short-term net revenues by identifying which customized orders to accept or reject, or to price such orders, so as to guarantee healthy margins. Such a change in using this System would require changes in business processes to support both the requisite analysis and negotiations with customers.

After improvements in a company's supply chain have been realized by implementing operational systems at the bottom of the Hierarchy, the three types of tactical planning systems in the middle of the Hierarchy offer the greatest opportunities for true integrated supply chain management. But, as we mentioned above, their implementation requires radical business process re-design. In particular, the organizational issues to be resolved when using a tactical modeling system on a repetitive basis include:

- What are effective IT and business processes for acquiring the necessary data from across the supply chain on a repetitive basis in a timely and accurate manner?

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- Who uses these data to perform tactical analyses?

- How can we successfully incorporate managerial judgment into plans suggested by the models?

- Once a tactical plan has been determined, how is it disseminated and implemented?

- How can managerial incentives be changed to reflect global efficiencies?

Space limitations prevent further discussion of these issues (see Shapiro (1998)).

3. Supply Chain Decision Databases

As we stated in the introduction, the application of any optimization modeling system in the System Hierarchy requires inputs from a supply chain decision database that is created by transforming transactional data found in the ERP, MRP and DRP systems. The decision database also contains data derived from the Forecasting and Order Management System. Furthermore, supply chain decision databases for the various optimization modeling systems overlap and should be created and managed in a holistic manner.

The importance of decision databases, their differences from transactional databases, and the optimization models they generate have been ignored by vendors of ERP systems. Either by omission or commission, they wrongly suggest that integrated supply chain management in the firm can be readily achieved once an ERP system has been successfully installed there. In the paragraphs that follow, we outline key principles for creating and exploiting decision databases. Space does not permit us to delve deeply into their form and content; see Shapiro (1993c, 1997, 1998) for more details.

3.1 Adapt Managerial Accounting Principles in Computing Costs

The information revolution has facilitated advances in **management accounting**, which is defined by Atkinson et al (1997; p. 3), as "the process of identifying, measuring, reporting, and analyzing information about the economic events of the (firm)" for the purposes of internal planning and control. Its focus is different than that of **financial accounting**, which is concerned with reporting historical results to external audiences. Financial accounting data is often inaccurate for the purposes of supply chain decision making because it employs allocations of indirect and fixed costs based on historical volumes that will change in the future.

The management accounting community has developed a new method called **activity-based costing**, which seeks to allocate indirect costs, otherwise called **activities,** to cost objects, such as product and customer costs. This allocation is based on **cost drivers** that determine how the activities contribute to the total cost of the cost objects; see Atkinson et al (1997) for more details and Elram et al (1994) for applications in logistics. Indirect cost drivers may be volumetric, such as a cost driver for the receiving department that equals the number of parts handled by the department during the planning period. They

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may also be non-volumetric, such as a cost driver for machine set-up costs that equals the number of times a machine is set-up during the planning period. The allocation of direct costs involves natural and obvious drivers, such as machine hours for machine cost, and is much more straightforward.

For the purposes of decision making, the managerial accounting or modeling practitioner must develop **cost relationships** of direct and indirect costs, rather than mere points estimates of them. These are functions that describe how costs will vary in the future as a function of the values of their cost drivers. Nonlinear and discontinuous functions of a single cost driver may be approximated by linear and mixed integer programming constructions. If a cost relationship involves multiple cost drivers with cross-product terms, nonlinear programming modeling techniques may be required.

The connection between activity-based costing and supply chain optimization models is important, but complicated. For our purposes here, the key construction needed to create costs for the supply chain decision database is a mapping of indirect costs in the company's general ledger into natural categories of supply chain costs with associated cost relationships, drivers and resources. A cost driver corresponds to a resource if its availability is limited. Otherwise, the cost driver is merely an accounting device for tracking costs.

A serious difficulty too often encountered by modeling practitioners when they wish to create an optimization model of a multiple facility supply chain is that, for historical reasons, the firm uses different accounting systems at each facility. The practitioner is then faced with the complex task of homogenizing and calibrating costs across facilities so that the optimization model will make even-handed comparisons when it computes an optimal plan. Fortunately, implementation of an ERP system in such a firm will eliminate these planning and modeling difficulties, along with many others.

Activity-based costing and optimization modeling play complementary roles in identifying costs and cost relationships for supply chain decision making. A supply chain optimization model provides a template for costs and cost relationships in terms of generic planning elements such as processes, resources, facility costs, and transformation recipes. Activity-based costing analysis of general ledger and other raw cost data determines, the specific nature of these generic elements, and parameters defining their cost relationships.

3.2 Aggregate Products, Customer, Suppliers

For the purposes of strategic and tactical planning, the modeling of supply chain operations should incorporate suitable **aggregations** of products, customers, and sometimes suppliers. It is not necessary or desirable to describe operations at the individual SKU level for the purposes of strategic or tactical supply chain analysis. Thus, a supply chain model for a retailing company may be based on 100 product families that are derived by aggregating the 50,000 SKU's sold by the company. The importance of product aggregation to effective modeling was recognized by researchers long before supply chain management became important; for example, see Zipkin (1982) and Axsater and Jonsson (1984).

Aggregation of products into product families is the most difficult type of aggregation. It requires wide and deep knowledge of the company's product lines. Products selected for a single family should have similar characteristics with respect to

supply chain costs, resource utilization, transformations, and so on. Fortunately, the practitioner need not force unnatural aggregations to ensure a manageable number of product families because the process is self correcting according to the 80/20 rule. Thus, a natural aggregation resulting in 250 product families may easily be reduced to 60 families by aggregating the 200 smallest families, which may constitute only 20% of total volume, into 10 miscellaneous families.

Customer aggregation may be done in a hybrid manner, depending on the company, the industry, and the scope of the modeling analysis. Large customers should be retained as separate entities, whereas several small customers in a confined geographical area can be aggregated into a market zone. Customer aggregation can be reversed by a post-optimality analysis that creates detailed management reports of customer sourcing plans. Supplier aggregations may be made in a similar manner.

To accurately capture planning details, aggregations must become less crude as we descend in the System Hierarchy. Still, the numbers of families of products, customers and suppliers should remain manageable due to the decreasing scope of the models. Even for scheduling models, product aggregation may be necessary and desirable. For example, when scheduling production on a paper machine, the difficult decisions are when to make major changeovers from one type of paper to another and how much total volume of the new type to produce. By contrast, optimizing the sequence of grades to be produced within a given type is straightforward and does not require a model. Thus, in this case, the scheduling model can ignore details about product grades. Once an optimal plan has been computed, a simple post-optimality routine can be applied to determine the timing and size of production for the various grades.

3.3 Incorporate External Data About
Suppliers, Markets, the Industry and Domestic and Foreign Economies

This requirement of the supply chain decision database reminds us of the obvious fact that transactional data about the company's operations is not sufficient in scope for supply chain analyses of a strategic and tactical nature. Depending on the analysis, an optimization model will require data about supplier costs and capacities, and market conditions for the company's products. For strategic planning purposes, economic data about long-term prospects for the company's industry and national economies in which the company operates its supply chain may also be required.

3.4 Develop Data Describing the Future

As we discussed in the introduction, transactional data in ERP, MRP and DRP systems portray the firm's past and present, whereas analytical data in the supply chain decision databases address the firm's future. These data describing future operations of the company must be extrapolated from historical, transactional data. The extent of this extrapolation is greatest for strategic planning, but some extrapolation may be needed even for scheduling purposes; for example, short-term forecasting of demand from large customers who have not yet placed firm orders.

Uncertainty about the future, especially as it relates to strategic planning, can be analyzed by optimizing the models under different scenarios of data. Scenario construction must be based on managerial judgment about the firm's major areas of

strategic initiative. The emerging discipline of scenario planning proposes guidelines for these constructions; for example, see Georgantzas and Acar, 1995.

At virtually all levels of planning, the supply chain decision databases will contain data describing options not currently included in the company's operations. Strategic options might include potential acquisitions or mergers, the construction of new facilities, the development of new technologies, or supply chain planning for a new product. Tactical options might include supply contracts with new vendors, or manufacturing exchange agreements with other firms.

Preparing data to evaluate such options is not simply a matter of forecasting or extrapolation. For example, evaluation of a potential acquisition requires integrating its supply chain decision database with the decision database of the company to create combined inputs for an optimization model of the merged supply chains. Similarly, a model to evaluate the re-design of a distribution network needs data describing the locations of potential distribution centers, along with costs for constructing or renting facilities in these locations, and transportation rates from these locations to the company's markets. In summary, the decision database often requires data about supply chain options for which the firm has no historical data.

3.5 Incorporate Parameters Reflecting Management Policies

Supply chain analysis at all levels of planning requires data and structural inputs reflecting company policies and managerial judgments about risk. The decision database must be extended to include these data, and optimization models require decision variables and constraints that mechanize them. For a global corporation planning its strategy for next year, the CEO may wish to impose a constraint limiting the manufacture of any product family at any single facility to no more than 75% of total forecasted volume for the year.

For a distribution company developing its tactical plans for the coming quarter, the VP for Marketing and Sales may wish to limit the maximal distance between any distribution center and any market it serves to 300 miles, which roughly equals the limit of one day deliveries. For a manufacturing firm, the Manufacturing VP may wish to limit the dollar volume of out-sourced production for next year in a particular department to no more than 25% of the department's annual budget. For a company making local deliveries of products, the general manager may wish to limit the number of part-time drivers scheduled each week.

In performing strategic and tactical analyses, model structures reflecting management policy such as these may be soft implying the need to make several model runs to measure the tradeoffs of cost or revenue against the other criteria. Such multi-objective analysis requires the managers to specify a range of permissible values for the non-monetary criteria. On the other hand, for scheduling applications, the tradeoffs among criteria must be hard-wired to ensure rapid computation of a final plan for execution.

3.6 Integrate Model Outputs with Model Inputs

A supply chain decision database will include output from an optimization model as well as the inputs used in generating it. This data integration has a few subtleties although it is mainly straightforward. Only non-zero output data need be stored, such as the positive flows of products from the distribution centers to the markets. Moreover,

technical output, such as values of zero-one variables, can be suppressed. The values of shadow prices on resources and reduced costs on activities are useful data. They need to be combined with the appropriate input data on resources and activities.

3.7 Provide Graphical Displays and On-line Analytical Processing of Model Inputs and Outputs

For strategic and tactical supply chain planning, it is important that an optimization model system provide graphical displays of data, including graphical mapping of inputs and outputs using a geographical information system (GIS). These displays do not add to the system's inherent analytical capabilities. Still, they are very useful for communicating data, problems and solutions, especially to managers who may be too busy to study detailed, tabular data. Camm et al (1997) report on a successful modeling study of Procter and gamble's supply chain that relied heavily on graphical mapping displays to extract judgments from product strategy teams.

For a company doing business in the continental U.S., a GIS would be used to display the results of a logistics network design analysis. For example, the GIS could produce a map of the U.S. for each product showing

- the optimal location of distribution centers supplying the product
- color-coded data indicating which markets are served by each distribution center
- links of variable thickness indicating the relative flows of product between distribution centers and markets

For scheduling applications, graphical displays allow human verification and manipulation of plans computed by an optimization model. An open issue is the appropriate level of human interaction with the scheduling system. The present style of many systems relies too heavily on such interaction. As a result, scheduling plans are inferior to those that could be found by rigorous optimization models and solution methods. Moreover, the human scheduler may spend excessive time manipulating trial solutions to find one that is acceptable. A related difficulty is that off-the-shelf scheduling systems rely too heavily on the human scheduler to customize solutions to the company's scheduling environment. In many cases, the company would benefit significantly by investing in a more expensive scheduling system with customized analytic methods.

On-line analytical processing (OLAP) refers to the application of data management and data mining tools to organize, analyze and display complex input and output databases. A key feature is Multidimensional Data Viewing (MDV), which allows an analyst to develop graphical displays of complex data in a relational database. This capability is also valuable for comparing and contrasting plans for multiple scenarios.

4. Conclusions

Applications of the optimization modeling systems for integrated supply chain management discussed in this paper are work-in-process. In many companies, ambitious tasks to implement ERP systems, and other transactional and analytical systems at the bottom of the System Hierarchy of Figure 1, have yet to be successfully completed. It is

not surprising, therefore, that most companies have not seriously begun initiatives for moving up the System Hierarchy to develop and use optimization modeling systems for tactical planning.

Similarly, the number and scope of applications of systems at the top of the System Hierarchy continues to grow, but we have seen few initiatives to move down the Hierarchy to develop and use optimization modeling systems for the same or related tactical planning problems. For companies that have successfully used strategic optimization modeling systems to perform studies, the lack of interest in extending them to tactical applications is particularly frustrating for modeling practitioners. From a technical perspective, such extensions are easy to accomplish once the studies have been performs because they involved validation of the model and creation of the supply chain decision database.

This reluctance is not surprising since repetitive use of a tactical optimization modeling system requires considerable business process re-design. Moreover, tactical applications require the development of permanent supply chain decision databases, which, as we already observed, are not yet well understood. Despite the difficulties, we can be optimistic about the ultimate breakthrough of tactical modeling applications because the potential rewards are so great. Such applications in a given company may stem from either extensions of bottom-up or top-down system evolutions.

An important issue that merits further investigation, which is closely related to those discussed above, is the extent and sustainability of competitive advantage accruing to a firm as the result of transactional and analytical IT used to integrate its supply chain activities. The academic community has suggested that IT innovations are necessary, but not sufficient, for achieving competitive advantage (Mata et al (1995), Powell and Dent-Metcallef (1997)). They must be combined with complementary organizational and business initiatives if competitive advantage is to be achieved. This observation is consistent with the approach taken by most software firms offering systems in the System Hierarchy. They seek to sell their systems as off-the-shelf commodities, thereby providing all companies with the same capabilities and little competitive advantage. They are reluctant to customize their systems to the peculiarities of supply chain management in a client company because multiple, customized systems are difficult to support. Some companies have come to realize that it pays to invest in customization of selected components of the System Hierarchy, as well as in training and business process re-design that allows IT to be more fully exploited.

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