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THE INTEGRATION ASPECT OF SUPPLY CHAIN MANAGEMENT: A FRAMEWORK AND A SIMULATION*

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The concept of supply chain management seems to be an essential element in many of today's operations and logistics management programs. Yet, there is still a lack of integrative frameworks and teaching tools that specifically tie together different supply chain concepts. This paper has two specific objectives. First, we describe an intuitive hierarchical framework that instructors can use as a convenient "road map" to classify and categorize supply chain concepts. Second, and also the focal point of this paper, we describe in detail a tool, the Supply Chain Simulator (SCS),which helps the student appreciate the scope of decisions that need to be made and their impact on managing today's complex supply chains. The supply chain simulator is based on the hierarchical approach, and has been successfully used to teach supply chain management to students at the undergraduate, MBA, and executive levels.

(SUPPLY CHAINS, PEDAGOGICAL SIMULATION)

1. Introduction

Since the term "supply chain management" (SCM) was coined by Houlihan in 1985 (Houlihan 1985), it seems to have taken a life of its own. Those of us who research and teach SCM agree that the concept refers to a set of networked organizations that work together to source, produce, and ultimately distribute products and services to the customer. However, the nature of cooperation between firms has been widely discussed, from a variety of angles, by different members in the supply chain under different names. "Efficient Consumer Response," "Quick Response," "Integrated Logistics," "Channel Management," "Just-In-Time Retailing," and "Value Chain Management" seem to be some of the popular terms that attempt to describe the concept of integrating some or all of the constituent links in the supply chain. Bowersox, Closs, and Helferich (1988) put forward the concept of SCM that is perhaps most relevant to our discussion:

> . . . a single logic to guide the process of planning, allocating, and controlling the financial and human resources committed to physical distribution, manufacturing support, and purchasing operations.

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We will interpret this to mean greater coordination of activities—both planning and control functions—across the entire chain, and just between a few of the chain members. Additionally, we view supply chain management as a compromise between full vertical integration in the channel, where the material, information, and cash flows are entirely owned by a single firm; and total independence of the several firms operating in series in a channel. The central premise in SCM is that strategic and tactical coordination between the various players in the chain is the key to providing effective customer service, and often leads to substantial improvements in logistical performance and shareholder wealth.

The increased importance of SCM/logistics has led *US News and World Report* (October 27, 1997, p. 104) and *Working Woman* (February 1999, pp. 42–51) magazines to cite it as the hottest career track for business majors. Jobs such as "Customer Supply Chain Manager," "Logistics Engineer," "Vendor Managed Inventory Coordinator," "Business Process Consultant," etc. require the interested student to be trained explicitly in concepts that integrate the various firms, functions, and technologies in the supply chain [see, for example, the career guide of the Council of Logistics Management (CLM)]. Although several schools have well-developed integrative courses, there is still a lack of integrative frameworks and tools that specially tie together different supply chain concepts. There are several textbooks available today, specifically at the undergraduate level of instruction, that have many of the essential elements, but are weak in explaining some of the links in the supply chain, or do not show how the various elements in the chain are linked together. Still several other schools have successfully implemented "tool-based" courses in SCM. These train the students on a variety of aspects in SCM, but sometimes fail on the integration aspect.

This paper has two specific objectives. First, we describe an intuitive, hierarchical approach that in our experience is well suited to teach both the strategic and operational issues in supply chain management. The hierarchical approach is comprehensive yet loosely structured, making it easy for the interested instructor to easily adapt it to suit his or her needs. Second, and also the focal point of this paper, we describe in detail a tool, the *Supply Chain Simulator* (SCS), which helps the student appreciate the scope of decisions that need to be made and their impact on managing today's complex supply chains. The supply chain simulator is based on the hierarchical approach and has been used successfully to teach supply chain management to students at the undergraduate, MBA, and executive levels.

The remainder of the paper is organized as follows. The second section gives an overview of the hierarchical approach around which we structure our SCM course and the SCS. The third section describes the general nature of our course and gives a brief narrative of the environment in which we run the SCS. The fourth section describes the logic behind the simulator and how we implement it in our classes. The fifth section presents some thoughts we have about extending the usefulness of the simulator. We conclude with a summary of the paper.

2. A Hierarchical Approach to Achieving Supply Chain Integration

Clearly the idea of supply chain management is to view the chain as a total system, and to fine-tune the decisions about how to operate the various components (firms, functions, technologies, and activities) in ways that produce the most desirable overall system performance in the long run. Doing so is extremely difficult because of the number and complexity of the decisions to be made, as well as the inter- and intraorganizational issues that must be addressed.

After working with many companies dealing with these issues over the years, we believe that a four-step hierarchical approach is best suited to teach the seemingly endless set of decisions and initiatives that apparently seem to be classified under the umbrella of supply chain management. Our intent here is not to provide a rigid framework but more to illustrate a loose and flexible "road map" that instructors can use to classify and categorize supply

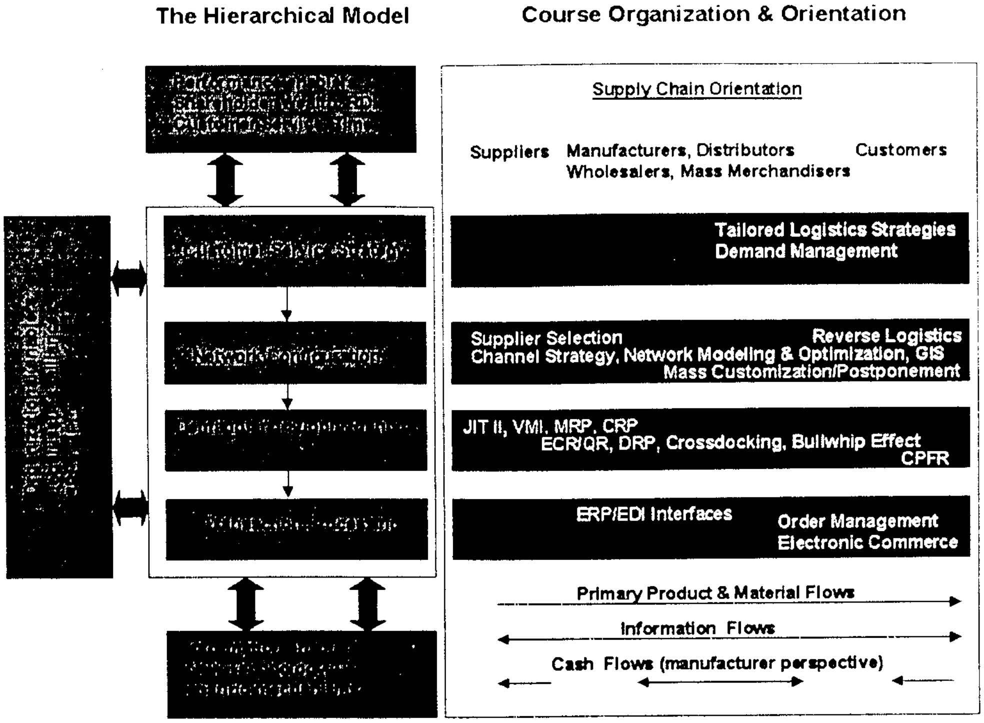

FIGURE 1. Sample Course Design.

chain concepts. The simulation tool we describe later in the paper is also based on the following hierarchical model.

The origins of the hierarchical approach go back to Anthony (1965) and Hax and Meal (1975). The fundamental idea behind the approach is to first do high-level, or strategic, planning on an aggregate basis, and then develop lower-level (and more detailed) plans within the constraints laid out by the higher-level planning (Stenger 1987).

Figure 1 summarizes the hierarchical model. Additionally, it also shows how the model is related to the general organization of our supply chain management course.

Step 1: Customer Service Strategy

It is our premise here that the firm has already gone through the process of establishing a corporate-wide business strategy, i.e., has well-determined lines of business, core competencies, growth objectives, and stakeholder commitments. From a supply chain strategy perspective, the execution of the business strategy will involve understanding and setting customer service requirements of each product-market segment, identifying opportunities for differentiation (Shapiro 1984), and deciding on strategic responses to customer requirements to maximize revenue with the most efficient use of capital resources. Students appreciate that with a well-defined supply chain strategy, it is possible to substantially improve the seemingly conflicting goals of shareholder wealth and customer service.

Step 2: Network Configuration

This step primarily involves the determination of the supply chain network, i.e., choosing the channels of supply and distribution (Fisher 1997), and defining the best supply chain network options and associated costs of offering varying levels of service. This includes choosing the optimal number, location, role, associated linkages, and aggregate plans of each channel partner. Once the supply chain network is defined and put into place, it very much determines the levels of service it can provide to customers.

When we teach network configuration, we identify the different product, information, cash, and process flows in the supply chain, and analyze how we can position resources to optimize these flows. For example, if the customer service strategy is growth oriented with a premium on mass-customization, the product flows can be altered by several means—such as postponement or process reversal—to optimize for this strategy.

Step 3: Demand and Supply Planning

This stage of planning determines the exact flow and timing of materials such as raw material release to manufacturing facilities, or finished goods to the distribution centers or customer markets. The network configuration phase has already determined the locations, origins, and destinations of these material flows. The material flow and timing decisions are typically arrived at by using time-phased, or requirements planning, techniques, working from the forecasted demand back through the supply chain to the raw material sources. Additionally, examples abound (and we use them as a backdrop when teaching) of firms using specialized demand and supply planning procedures: Collaborative Planning, Forecasting, and Replenishment (CPFR), Efficient Consumer Response (ECR), and Quick Response (QR) on the outbound side; and Vendor Managed Inventory (VMI), Continuous Replenishment (CRP), and JIT II on the inbound side.

Step 4: Transaction Processing and Short Term Scheduling

Customer orders arrive at random, and they are assigned to a predetermined (by supply chain configuration methods) location and carrier. The flow of this order (timing and quantity) through the supply chain is already determined by the demand and supply planning process. Transaction processing is therefore more like a day-to-day accounting system, tracking and scheduling every order to meet customer demand. Sample transactions include order entry at the retail markets, physical replenishment and order fulfillment of the goods at the distribution centers, and material releases and purchase orders at the manufacturing facility.

As Figure 1 indicates, supply chain integration is facilitated by three key factors. First, the emergence of new technology and the ability to share information between channel partners has greatly enhanced existing operational efficiency of participating firms. For example, the emergence of the Internet has spawned a genre of direct-to-customer distribution channels. Additionally, initiatives such as CPFR, made possible by recent advances in Web-based communication, make even the traditional channels of distribution extremely efficient, resulting from the improved ability to share accurate information between channel partners in "real time."

Second, in the face of globalization and technological change, firms are increasingly experimenting with different organizational options. Examples abound of "strategic alliances" (like GE Appliances and Ryder Logistics) that match up core competencies; or innovative outsourcing arrangements such as Andersen Consulting's Fourth Party Logistics (4PL) concept. In many cases, an overabundance of core-competencies or the emergence of a new distribution channel have led to spin-offs that allow the establishment of smaller and more manageable supply chains (see Giles and Hancy 1998).

Third, firms are increasingly realizing that partnering with channel members—either at a strategic level, like setting up dedicated alliances or at an operational level such as information sharing—improves cash flows and consequently shareholder value. Benetton (quick response), Wal-Mart (everyday low prices), and Hewlett-Packard (product postponement) are outstanding examples of companies who have increased shareholder wealth by effective supply chain management. For example, in the PC industry, the postponement of assembly to the distributor from the manufacturer increased the Economic Value Added (EVA) from 0.4 to 1.6% of sales for the distributor (Evans and Danks 1998)!

In our experience, a good number of firms, either explicitly or implicitly, have been evolving toward the hierarchical approach over the years. Examples include Alcan Aluminium, Citgo Petroleum, Dow Chemical, Millennium, and Digital Equipment Corporation. Some of the firms, DEC for example, do not necessarily follow a strict hierarchy; rather they attempt to solve all or at least a majority of the levels simultaneously. Furthermore, several of the supply chain software vendors provide a suite of software options, each addressing a level or a group of levels in the hierarchy. For example, CAPS Logistics has the Supply Chain Designer that addresses the first two levels of the hierarchy and the RoutePro, which is primarily a short-term scheduling utility (references to the software taken from CAPS Logistics' marketing literature).

3. Course Design and Simulation Narrative

The use of hierarchical models to teach operations classes is not new (see the framework in Vollman, Berry, and Whybark 1992). Our perspective on the hierarchical approach is broader in the sense that it explicitly considers supply chain strategy, customer, and shareholder issues. Additionally, we cut across firm boundaries to include all the relevant firms, activities, organizations, and technologies that make up the supply chain. We know at least five business schools that explicitly use or plan to use the hierarchical model we have presented—Penn State, Ohio State, University of Tennessee, College of William and Mary, and the University of Cincinnati—all of whom traditionally have had strong logistics and supply chain programs at the undergraduate, MBA, and executive levels of education.

At the MBA level, the course is taught as a case-oriented one, supplemented with readings (typically from business magazines and trade journals), in-class exercises, and minilectures that relate to specific topics shown in Figure 1 (details are available from the authors). The Appendix shows a sample MAB course schedule developed around the hierarchical model. A similar outline is used for our undergraduate classes, except that the readings are replaced by chapters from popular logistics textbooks (e.g., Ballou 1999). We use the hierarchical approach in our executive programs, but because of time constraints, not in the detail described in Figure 1. Rather, we typically limit ourselves to any one level of the hierarchy or a specific topic (say Electronic Commerce) in supply chain management. At all levels of instruction, however, we make a deliberate effort to show how each topic cuts across firm boundaries and, in many cases, across different levels of the hierarchy.

In our experience, the hierarchical approach gives students an integrative framework around which they can build their understanding of SCM. The primary purpose of the hierarchical approach, as we see it, clarifies how the various elements and concepts in supply chain management are linked to each other.

In addition to an integrative framework, however, the student also needs hands-on experience where he/she can actually experience realistic situations in which such a framework is used. To meet that objective we have authored a comprehensive tool, the Supply Chain Simulator (SCS), programmed in Visual Basic (a programming system for the Windows platform), that uses the hierarchical approach in simulating the operation of a supply chain under a number of alternate environments.

Our specific goals in developing and using the SCS were:

1. To provide the student a tool to analyze supply chains that is comprehensive (i.e., that includes most of the relevant costs and constraints), and that captures the essential elements of product, information, and cash flows in the supply chain.
2. To provide a set of supply chain metrics—including those of cost, customer service, time, and shareholder wealth generation—that the student can use to evaluate alternative supply chain configurations.

The SCS simulates the long-term operations of a supply chain under a number of environments and configurations. As the ensuing discussion shows, the simulator allows the student to alter:

(1) strategic elements of the supply chain network, i.e., the constituent customer markets, distribution centers, plants, supplier locations, and transport modes; (2) tactical elements such as forecasting options, demand and supply planning options; and (3) the more operational elements such as the safety stocks and planning horizons at every constituent facility. Based on student decisions, the SCS generates a detailed report, giving performance at each facility and, more important, key supply chain metrics that the student will use to evaluate the efficacy of the chosen supply chain plan.

We use an unpublished case "MAS Manufacturing" (for details see Ganeshan and Stenger 1999) as a companion to the SCS. The case is a result of a long-term project that one of the authors of this article was involved with. The case is about the design and operation of a supply chain for a firm, called "MAS" for the purposes of this discussion.

The case describes a company operating in a typical supply chain for fast-moving consumer goods. The simulation focuses on the individual firm within a supply chain context, because the unit of analysis will continue to be the firm for most students once they are in the workplace. If the individual firm cannot make itself viable within the supply chain, then it puts itself in danger of going out of business. In the simulation, the firm in question can alter its relationships with its customers and suppliers, as well as its internal operations, so that both it and the supply chain can improve their joint performance.

We give a brief narrative of the case so the reader can appreciate the scope and the depth of the decisions the SCS helps students make.

Abridged Simulation Scenario Narrative

MAS produces a line of household cleaners, chemicals, and associated accessories in Denver, Colorado. These products are currently sold in the West and Midwest, but not on the East Coast. Founded in the early 1950s, the company has had its ups and downs as it has struggled toward stable, profitable growth. The president and CEO recently asked her top managers to consider the best way for the company to "bring our growth under control so we can increase profits and return on investment." We provide the students with Figure 2, which shows the background conversations in the case.

PRODUCTS AND MARKETS. The MAS line of household cleaners and chemicals is sold primarily at the retail level through grocery and discount channels. We provide the student with the current supply chain for MAS (see Figure 3). The company has no direct sales force, but rather uses food brokers to sell to customers on a commission basis. Ten district sales managers are located around the market, each supervising several brokers. Although the company promotes sales in a variety of ways, its primary promotional expenditures are devoted to television, with spot ads on afternoon soap operas and late night news programs.

We also provide the students with the price of the product (which is constant across markets), FOB terms, and the annual demand and associated seasonalities in each of these markets.

THE DISTRIBUTION SYSTEM. Because of the large number of Less than Truckload (LTL) shipments to customers and the long distances to be covered, MAS has several distribution centers (DCS), which are located in Los Angeles, CA; Denver, CO; Dallas, TX; Chicago, IL; and Detroit, MI.

The distribution centers are resupplied primarily by rail to reduce transportation costs. The students are given the option of choosing between rail Boxcar loads or Trailer on Flat Car (TOFC, also known as "Piggy-back"), each with different costs of shipping. The students are also given the option of shipping by truck at LTL or the Truckload (TL) levels. In addition to the operating economies of the DCS (investment, and fixed and variable costs for several levels of throughput), the transportation rates and lead-time statistics for each of the transport modes are provided to the student. These obviously differ for each origin and destination pair (lane).

The inventories at the distribution centers are controlled in the "base case" by means of reorder points. Whenever an item's inventory level at a DC reaches its reorder point, a

Exhibit 2: Background Conversations in the Case

Helen Clark (CEO): You've all had a few days to think about my challenge–and it's something you should have been wrestling with anyway–so what have you come up with?

Dick Strickland (V.P. Production): There is no question that we can produce more than we are selling. Projections for sales next year are 18.5 million pounds of product, and I could squeeze almost 27 million pounds out of the plant if we needed it. I think we should start selling in the East. The incremental production cost would only be around $.43 per pound. And we can sell it for two dollars a pound.

Beth Rankin (Director of Distribution): That may be true, but the freight costs are going to eat us up. I think we should stay in our market territory and use the excess production capacity in Denver for meeting peak period demands. That would reduce inventories substantially compared to what we have now with all your production smoothing–and we all know what it costs to carry inventory these days. We're manufacturing a lot of product before we need it.

Linda Cole (V.P. Marketing): I'm all for expanding sales, Dick, you know that. But I think we're going to have to have an East Coast plant if we expect to penetrate that territory. Not only will that cut Beth's freight and reduce inventories; it will also give our customers a second source, reducing the likelihood that something will disrupt their supplies. Anyway, that market is bigger than our Denver plant alone can handle.

Strickland: Yes, but you're talking about a lot of money for an entirely new plant, and we would still be stuck with excess capacity in Denver. Maybe we should try to penetrate only part of that market.

Stan Penzotti (Director of Purchasing): I know a new plant in the East would be expensive, Dick, but it would sure make our raw material sourcing a lot easier and cheaper. We would be near many of those water-supplied terminals. It would probably reduce our raw material costs by 5 to 10 percent. And we could design out some of those bottlenecks we have in the current plant.

Clark: Those are some interesting ideas, but I'm not so sure we are currently operating as efficiently as we should. What about the way we are currently servicing our customers? Is that holding back sales? Or how about those inventories? Do we really need a plant warehouse in addition to the distribution centers? Maybe we should expand; but before we go any farther, I think we need a serious study of the alternatives.

FIGURE 2. Background Conversations in the Case.

resupply is requested from the factory warehouse located in Denver, CO. The factory warehouse, meanwhile, forecasts DC requirements in the future. However, students are given an option to invest in a collaborative forecasting and planning (CFPR) system. This system

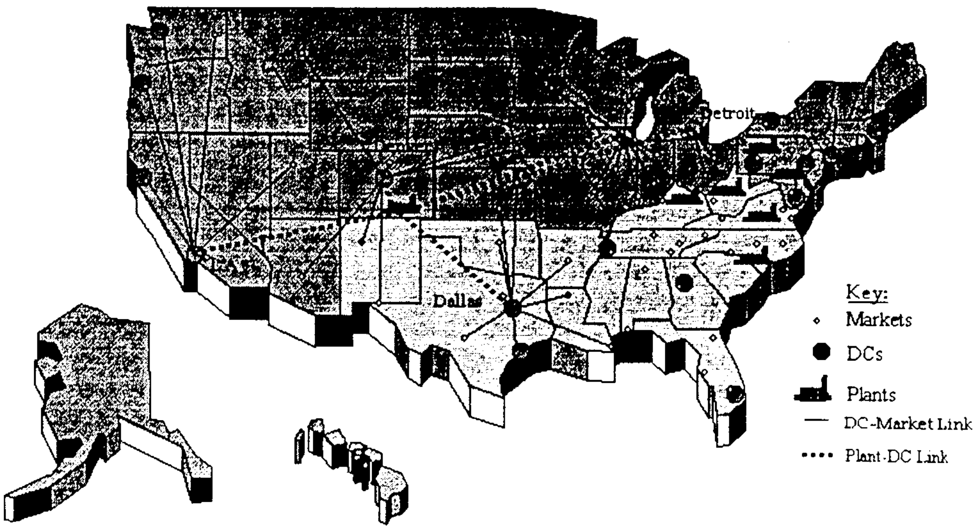

FIGURE 3. The Current MAS Supply Chain.

allows cooperation with customers to improve forecasts and replenishments through greater downstream visibility of demand and inventory positions. Furthermore, the approach uses distribution requirements planning (DRP) techniques to do the time-phased plan. The forecast errors, both at the DCS and the factory warehouse (when students do not choose to use the CPFR system), are used in computing safety stocks and reorder points. We provide the student with historical data on forecasting accuracy.

PRODUCTION. MAS currently uses one plant located in Denver to satisfy all its distribution needs. The capacity at the Denver location is close to 27 million pounds of product per year. This assumes 7 days a week, 24 hours a day operation (21 eight-hour "turns" per week). In general, the plant can turn out 25,000 pounds of product in an 8-hour work turn, allowing for standard preventive maintenance procedures. Adding afternoon, midnight, and weekend turns increases many of fixed and variable costs of production. This is the result of wage premiums required for extra shifts and weekends, as well as the increased wear on the equipment. We provide the student with operating economies—fixed and variable costs at various capacities—to run the plant.

It is also possible to purchase some adjoining land and expand production operations in Denver. The expansion would involve not only new facilities but also some revamping of the old facilities. The overall result would be to reduce variable costs. The students are provided with detailed expansion economies also.

After a good deal of study, six sites have been selected as potential locations for a new plant in the East. These are: Covington, KY; Parkersburg, WV; New Kensington, PA; Allentown, PA; Richmond, VA; and Raleigh, NC. Any new plant will use a new technology, so that even though Eastern labor costs may be higher than those in Denver, less manpower will be used. The operating economies (investment, fixed, and variable costs for varying levels of production) are also available to the student.

Also located at the Denver plant is a warehouse for holding raw materials and finished goods. The finished goods stored there consist of stocks used for replenishing the distribution centers, and stocks resulting from production smoothing. There is a possibility to eliminate the Denver plant warehouse to save on investment and operating costs. In this case, product would be allocated to the distribution centers as it comes off the production line. It is undecided at this time whether to include a plant warehouse in any new Eastern plant. The costs of operating the Denver plant warehouse (and the associated sunk investment allocated to it) are also available as are the ones at the six new locations.

PURCHASING AND SUPPLY. The case also allows the students to plan the procurement of three raw materials, Cans/Bottles, Chemicals, and Corrugated. We give the students the locations of the suppliers; they are typically located on the Gulf Coast, but they also operate water-supplied terminals on the East Coast and in major cities along the Mississippi and Ohio Rivers.

The prices, FOB terms, and the cost and performance statistics of the transportation modes (rail boxcars, TOFC, TL, and LTL) from each of the suppliers to Denver and the six potentially new ones are available to the student.

4. Simulation Logic and Implementation

A Brief Explanation of How the Simulator Works

Figure 4 illustrates the basic hierarchical logic that is used to program the SCS. We give only a brief explanation of the logic. The SCS first reads all the data required by the simulation. This includes the products, markets, and sales data; detailed data on the operating economics of each facility in the supply chain; the freight options, cost structure, and delivery performance of each of the transportation modes. The student then completes the network design phase of the hierarchical model through a graphical user interface (GUI; see Figure 5). The

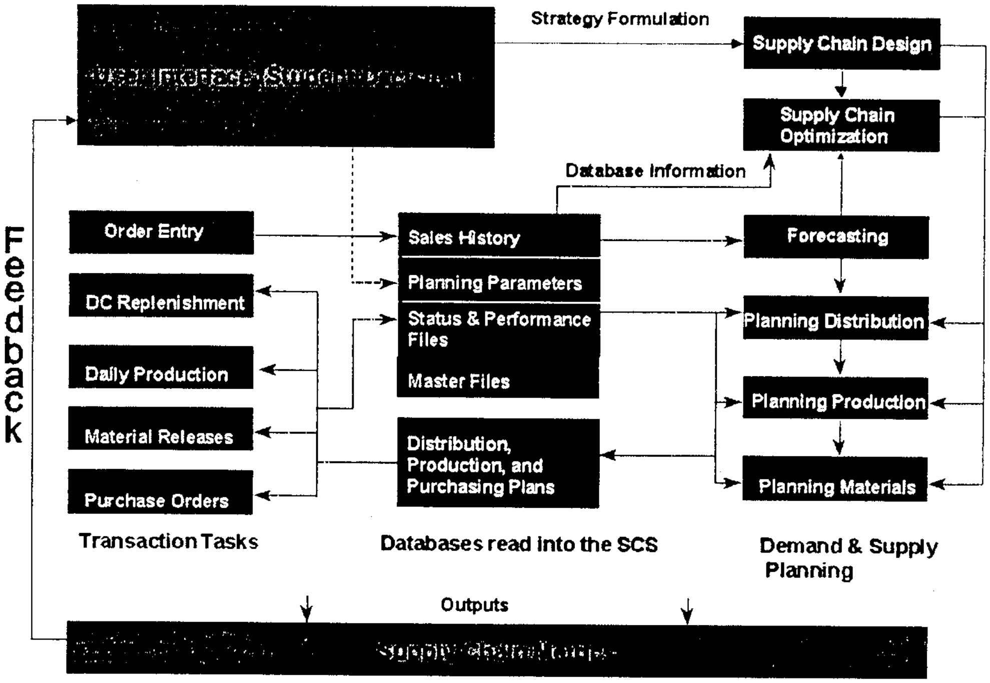

FIGURE 4. The SCS Logic and Simulation Program Flow.

data, together with the design and planning parameters input by the student (as the ensuing discussion shows, they are forecasting methodologies, safety stocks, time fences, etc.), define the nodes and operating procedures of the supply chain. We have written a simple network optimization routine that determines how the resources are allocated in the supply chain, i.e., allocation of customer markets to DCS, DCS to plants, and plants to suppliers (i.e., we help the student fill the "arcs" in the supply chain network). At the end of this stage, the physical supply chain is completely defined, i.e., nodes and the corresponding arcs between them are determined.

Our planning horizon is 13 periods (1 year), each period consisting of 20 days. At the beginning of the planning period, demand is forecast at each of the DCS, safety stocks are updated to match the desired service level, and distribution plans are generated at every DC. The result of the DRP is the determination of the DC needs in each time period of the planning horizon (13 time periods). The needs are then appropriately aggregated at the supplying plant warehouse and a feasible warehouse-shipping schedule is generated. In turn, this schedule generates a need for finished goods in every time period, and thus a production plan is produced that satisfies the needs over the planning horizon. The plan is smoothed, if necessary, to satisfy any capacity constraints. The production plan serves as the starting point for the supply planning process, which results in the determination of raw material needs and supplier-shipping plans.

Once the plans are computed for the entire time horizon, the SCS begins daily simulation until the end of the current planning period (1, 2, or 3 months, depending on the time fence), collecting supply chain performance data every day of the simulation. Once the next planning period is reached, the planning cycle is performed again, i.e., the DC forecasts are updated, distribution and supply plans are generated, and so on. In our simulation model, after an initial warm-up period (to allow for initial conditions), statistics are collected for 3 years to average random effects.

At the end of the simulation the SCS furnishes the student with detailed financial (fixed, variable, and investment costs) and logistical (service levels, inventories, and capacity

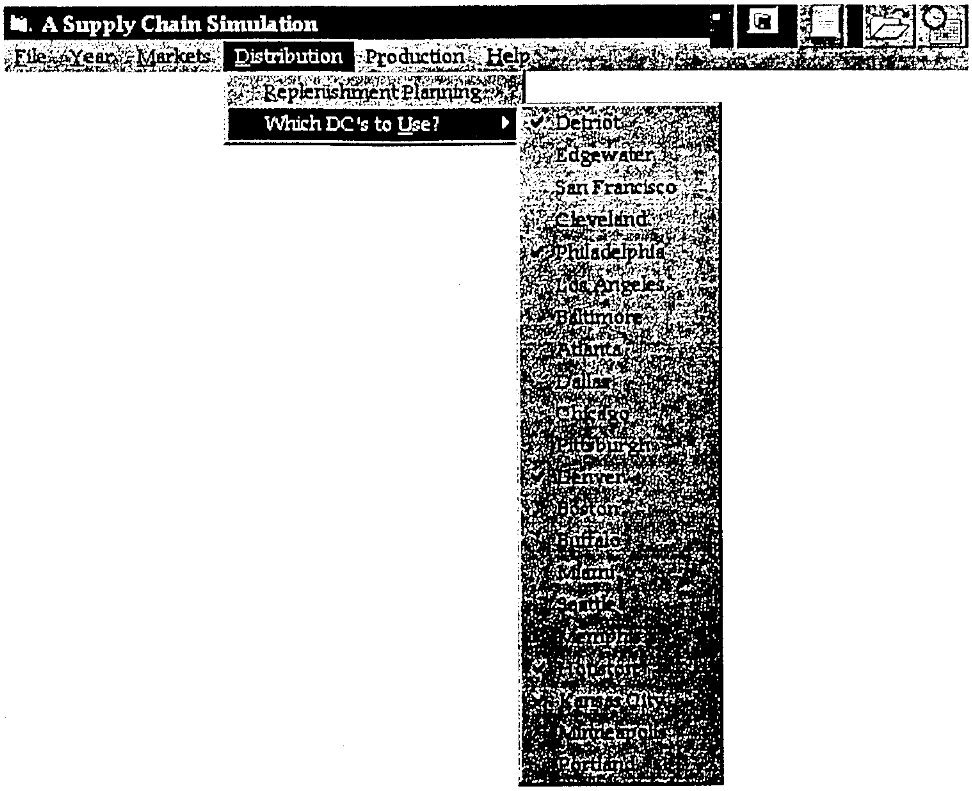

FIGURE 5. The Simulation Visual Interface.

utilization) performance at every facility in the network. In addition we provide detailed supply chain metrics, categorized by activity (see, for example, Figure 6). The metrics include both time and cost factors that relate to how responsive and cost effective the current supply chain plan is. The SCS report also includes what have come to be known as "Boardroom Metrics" (see Tyndall, Gopal, Partsch, and Kamauff 1998), such as return on investment (ROI), EVATM, profit contribution, customer service levels, and overall supply chain cycle time. In our experience such an activity-based metric system helps the student quickly identify potential areas for improvement in the supply chain.

Implementing the Simulation and Student Decisions

As the Appendix suggests, we typically structure the course so that the student, after an introduction to supply chain strategies, is introduced to the lower levels of the hierarchy. This prepares the student well for the first exercise using the simulator: making the current supply chain or the "base case" run more effectively. The student can alter the following parameters in the simulation:

1. *Retail or market-level forecasting methodology.* Students have a choice between two methods: one that simulates a DC-retail collaborative forecast that, although relatively expensive, produces lower forecast errors; and the other that simulates an independent DC forecast of the retail demand (of course, this is cheaper and produces higher forecast errors).

2. *Demand and supply planning method.* The students have the choice of using a collaborative planning and forecasting method (CPFR), in which the plants have visibility of DC requirements versus the order point method, in which the plant manager independently forecasts the DC needs. The CPFR initiative, of course, is the more expensive option as a result

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                        Activity Based Costs and Performance

                           Total Costs          Unit Costs  Time(days)

In-bound Activities

Purchase Costs             $30,527,566.00        $.8417
Freight Costs              $    672,913.33       $.0186
In Transit to Plant        $    189,509.38       $.0052         5.34
In bound Holding           $ 1,015,862.00        $.0280        28.30

Production Related

Plant Fixed Cost            $7,700,000.00        $.2123
Plant Var. Cost             $6,893,466.50        $.1901
WIP Holding                 $1,120,963.48        $.0309        10.00

Out-bound Activities

Plant Warehouse Fix Cost      $255,600.00        $.0070
Plant Warehouse Var Cost      $849,342.00        $.0234
Plant Warehouse Inv Cost      $977,162.31        $.0269        22.25
In Transit Holding to DC      $356,730.84        $.0098         8.12

Distribution

DC Freight In               $  591,688.78        $.0163
DC Fixed                    $  124,420.00        $.0034
DC Var                      $  528,421.21        $.0146
DC Holding                  $  328,449.13        $.0091         7.36
Freight to Customer         $8,635,699.02        $.2381
In Transit to Customer      $  198,799.92        $.0055         4.30

Administrative                $100,000.00        $.0028

Totals                     $61,066,592.00        $1.6838       85.65

                             Boardroom Metrics

                          Total Annual Costs         Cost / Unit
Total Sales               $72,534,534.12             $2.0000
Total Fixed               $ 8,180,020.00             $0.2255
Total Variable            $48,699,096.84             $1.3428
Total Inventory           $ 4,187,477.00             $0.1155

Profit Contribution       $11,467,942.12             $0.3162

Investment

Plants                                          $20,000,000.00
Plant Warehouse                                 $    900,000.00
Distribution Centers                            $ 1,244,200.00
Inventory                                       $ 1,094,830.38

Supply Chain Customer Service and Utilization Measures

Supply Chain Service Level:                     97.86%
Order Cycle Time to Customer                     4.30 days
Average Time through Supply Chain               85.65 days
Average Production Capacity Utilization         82.26%

Financial Performance

Profit Margin:                                  15.81%
Return on Investment:                           49.35%
Projected EVA:                                  $8,115,748.12
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FIGURE 6 Supply Chain Metrics (a Portion of the Simulation Output).

of the special information technology requirements. In effect the student trades off cost against the negative effects of the bullwhip phenomenon.

3. *Customer service levels.* The student sets the target "fill-rate" at every DC. The fill-rate is the fraction of the total retail (market) demand that is shipped from the DC inventory.

4. *Safety inventories of finished goods at plant warehouses, and raw material safety stocks at the inbound locations.* This gives the student an opportunity to examine the effect of inventory at various points in the supply chain.

5. *Time fences.* The student gets an opportunity to choose how often the material plans in the supply chain get updated. Of course, choosing a more frequent update policy is more expensive.

The students do the assignments in groups of three or four. The first assignment gives the student insight into the effects of the more operational elements on the performance of the supply chain. In our experience, the following are the key outcomes of the learning process. The participants:

- gain insights into the costs and benefits of collaborative forecasting and planning, both at the retail and the manufacturing level.
- understand the impact of holding inventory at various points in the supply chain. For example, holding relatively more finished goods inventory at the DCS (as opposed to the plant) is a more expensive option, but also has the highest impact on market or retail fill-rates.
- better understand the impact on fill-rates of more frequently updating demand and supply plans. Although updating the plans daily or weekly is more expensive than a monthly update, the students recognize that it produces a higher fill-rate on average.
- realize that even operational elements in the supply chain can have a significant impact on boardroom metrics. Most student groups show significant improvements in financial, time, and cost metrics as a result of operating the supply chain more effectively.

The second assignment asks the students to formulate a customer service strategy and configure the supply chain for the next 5 to 10 years. In addition to altering any of the five parameters discussed earlier, they have the option to:

1. Change market configurations: start selling in new markets and close certain markets down, if needed, to balance supply and demand.
2. Change DC configurations: close down some or all of the existing DCS and open new ones from the 21 potential sites available to them.
3. Open a new plant in the East, if needed, and set its capacity.
4. Change modes of transport in every constituent link in the supply chain.

Students learn during the course of this second exercise that it is possible to succeed with different customer service strategies. For example, a high-growth strategy would be to open new markets all over the United States in the next 5 years, build and operate a plant in the East, and establish several DCS to serve the increased demand. However, this is also capital-intensive, possibly resulting in low ROI and EVATM. A medium-growth and a high customer service strategy, on the other hand, would be to expand Denver's production, open select markets, and replenish them through nearby DCS with LTL shipments. Such a strategy, however, will produce lower profit margins resulting from controlled growth. The point is that students learn the delicate balance between costs, customer service, time, and shareholder wealth when they are formulating their strategies.

Second, students learn to appreciate the impact of production capacity on distribution operations, specifically inventory levels and fill-rates. Because of the highly seasonal nature of demand, the students need to plan enough capacity to build up inventory in time for the spring cleaning season.

Finally, this part of the assignment makes the students appreciate the impact of network configuration elements such as market, DC, and plant locations, and transport modes on supply chain performance. For example, although more expensive, a faster mode of transport decreases response time and cycle-inventories.

We use the two-assignment sequence at all levels of instruction. For both undergraduates and MBAS, we extend the process over several weeks. Because of the typical time compression in executive programs, we use a simplified version of the user interface with fewer degrees of freedom at the executive level. This allows us to complete the entire process in half a day. Unfortunately, this leaves little time to cover all the theory and techniques surrounding the case.

The feedback from students (at the undergraduate, MBA, and executive levels) has been very positive. Over the last 2 years we have had comments such as ". . . gives the big picture . . . ," ". . . great exposure to realistic situations . . . ," ". . . hands-on supply chain experience was wonderful . . . ," and the like. Additionally, such comments were also accompanied by high course evaluations! Executives find it eye-opening, to say the least. Most do not realize how much slack and waste might exist in their supply chains under the traditional functional approach to such operations. Furthermore, they have never really looked at the impact of supply chain initiatives on the "boardroom measures." Their usual response is, "How can I get a tool like this for my business?"

5. Discussion and Future Directions

The Supply Chain Simulator is a work in progress. Plans are underway to include the next version as part of a textbook on supply chain management to be published by Prentice-Hall. One of the important issues is for the students not only to see the results of their decisions, but also to understand why those results occurred. Right now the SCS is pretty much a "black box." Students set the input parameters and then view the final results. Obviously there is some temptation to revert to trial-and-error techniques. We caution students against this because, given the number of degrees of freedom, the trial-and-error approach is not a good use of their time. At the undergraduate and MBA levels, we are able to extend the process and cover the theory as we go through the various case assignments and subassignments. In fact we are adding to the number of assignments to further enhance the learning. At the executive level, given the short time frames of such courses, we are able to do less. Executives do tend to focus more on trial-and-error approaches because they seek quick results.

We are in the process of developing much more extensive graphical output of time series data so that students can see how the supply chain acts over time. In particular, they can view how various initiatives, especially cycle time reduction, tend to mitigate the negative effects of the bullwhip effect.

We are debating whether we should allow students to change parameters interactively as a run progresses. Then they could make corrections if they saw performance was not progressing as they had hoped. The disadvantage of this, however, is that it becomes even more difficult to explain why the results came out like they did. Another approach would be to provide some intermediate diagnostics that would let the student quickly abort a run in which, for example, she/he has not provided sufficient production capacity, or has made some other poor choice. In such a case the diagnostic needs to explain why the choice caused the problem (as instructors we are often called on to act in this diagnostic role, explaining why some results look illogical, but are in fact a natural consequence of the set of decisions made).

In any case the SCS is just one tool we use to try to explain and demonstrate the dynamics of supply chains. No one approach is sufficient, given the broad scope of supply chain management.

6. Summary and Conclusions

In this paper we have discussed an approach to teaching and demonstrating supply chain management concepts to students. The task is challenging because of the systems nature of the supply chain approach and the interrelationships between the various activities in the chain. The hierarchical methodology helps to simplify and structure the decisions that must be made in supply chains. In addition it provides an excellent "road map" throughout the course. Although it is true that synchronous planning techniques and advanced planning and scheduling tools are blurring the distinctions between the levels in the hierarchy, these approaches are made more apparent through the use of the hierarchical model.

The Supply Chain Simulator is particularly valuable in providing students with a way to see the impact on overall performance of the various decisions that might be made in designing and operating a supply chain. In addition they see the interrelationships between the various activities under different operating parameters. Students come away with a new appreciation for the need to do two things well in supply chain management. First, the right supply chain needs to be designed for the specific products and firm strategies in question. Second, they see the large impact on supply chain and firm performance when the resulting supply chain is operated effectively.

Our conclusion from this is that neither students, nor managers, can effectively design and operate supply chains without taking a total systems approach. And they cannot do this without decision support tools that can quantify the trade-offs between all the activities in the supply chain.[1]

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[1] We thank Professor David F. Pyke of Dartmouth College and two anonymous referees for insightful comments on earlier versions of this paper.

Appendix. Sample MBA Class Schedule (Details Available from Authors)

I. Customer Service Strategy

Ganeshan, "Four Steps to Effective Supply Chain Management," *Inbound Logistics*, February 1999. 16.
Fuller, O'Connor, and Rawlinson, "Tailored Logistics: The Next Advantage." (HBR Article: 93305)
Shapiro, "Get Leverage from Logistics." (HBR Article: 84313)
Case: Benetton (A) (HBS Case: 9-685-014)

II. Order Management

Shapiro, Rangan, and Svioka, "Staple Yourself to an Order." (HBR Article: 92411)
Kumar and Shraman, "We Love Your Product, but Where Is It?" *The McKinsey Quarterly*, 1992, 1, 24–44.
Case: Digital Equipment Corporation: Complex Order Management (HBS Case 9-690-081)

III Demand and Supply Planning: Customers, Products, and Distribution

Jain, "Forecasting at Colgate-Palmolive Company," *The Journal of Business Forecasting*, Spring 1992, 16–20
Tyndall, Gopal, Partsch, and Kanauff, *Supercharging Supply Chains*, Wiley: New York, 1998, 173–208.
Sharp and Hill, "ECR: From Harmful Competition to Winning Collaboration," in *Strategic Supply Chain Alignment*, Gower: Hampshire GU11 3HR, UK, 1998, 104–122.
Case: Procter & Gamble: Improving Consumer Value Through Process Redesign (HBS Case: 9-195-126)

IV. Pinacor/Tote double tour of the distribution Centers (CLM local roundtable event)

V and VI. Demand and Supply Planning: Manufacturing and Purchasing (2 sessions)

Fisher, Obermeyer, Hammond, and Raman, "Accurate Response: The Key to Profiting from QR," *Bobbin*. February 1994, 48–62.
MacDuffie and Helper, "Creating Lean Suppliers: Diffusing Lean Production Throughout the Supply Chain." (CMR Article: CMR090)
Case: Sara Lee: QR at Hanes (HBS Case 9-191-021)
Case: Campbell Soup: A Leader in Continuous Replenishment (HBS Case: 9-195-124)
Supply Chain Simulator Exercise I *Presentations: Improving the Base Case*

VII. Network Configuration: Product Flow Management for Mass Customization

Feitzinger and Lee, "Mass Customization at Hewlett-Packard: The Power of Postponement." (HBR Article: 97101)
Case: HP Deskjet Supply Chain (Stanford Business School Case)

VIII. Network Configuration: Transportation Choice and Planning Reverse Logistics Flows

Crum and Holcomb, "Transportation Outlook and Evaluation," in *The Logistics Handbook*, Robeson and Copacino (editors-in-chief); Howe (associate editor), The Free Press. 465–479.

Case: Frito-Lay: The Backhaul Decision (HBS Case: 9-688-104)

IX and X. Network Configuration: Network Modeling and GIS (2 sessions)

Bender, "How to Design an Optimum Worldwide Supply Chain," *Supply Chain Management Review*, Spring 1997.

Fisher, " What Is the Right Supply Chain for Your Product?" (HBR Article: 97205)

Camm, Chorman, Dill, Evans, Sweeney, and Wegryn, "Blending OR/MS Judgement, and GIS: Restructuring P & G's Supply Chain," *Interfaces*, January–February 1997.

Case: Kodak Business Imaging Systems Division (HBS Case: 9-693-043)

Supply Chain Simulator Design Exercise II: *Strategy Formulation and Network Configuration*

XI. Supply Chain Enablers: Information Systems (Enterprise Solutions)

Gries and Kasarda, "Enterprise Logistics in the Information Era." (CMR Article: CMR088)

Grackin and Dobrin, "Make Better Schedules," *Information Week*, April 21, 1997, 18–24.

Case: Vandelay Industries (HBS case, 9-697-037)

XII. Supply Chain Enablers: Information Systems (Electronic Commerce)

Rayport and Sviokla, "Exploiting the Virtual Value Chain." (HBR Article: 95610)

Rayport and Sviokla, "Managing the Marketspace" (HBR Article: 94608)

Case: Dell Online (HBS Case: 9-598-116)

XIII. Supply Chain Enablers: Organizational Structures

Gattorna, "Fourth Party Logistics: En route to Breakthrough Performance in the Supply Chain," in *Strategic Supply Chain Alignment*, Gower: Hampshire GU11 3HR, UK, 425–445.

Case: Laura Ashley and FedEx Strategic Alliance (HBS Case: 693-050)

XIV. Supply Chain Enablers: Performance and Course Wrap-up

Lambert, "Logistics Cost, Productivity, and Performance Analysis," in *The Logistics Handbook*, Robeson and Copacino (editors-in-chief); Howe (associate editor), The Free Press, 260–302.

Scott and Westbrook, "New Strategic Tools for Supply Chain Management," *International Journal of Physical Distribution and Logistics Management*, 1991, 21, 1, 23–33.

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TYNDALL, G., C. GOPAL, W. PARTSCH, AND J. KAMAUFF (1998), *Supercharging Supply Chains*, John Wiley & Sons, New York

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