Partner Selection and Synchronized Planning in Dynamic Manufacturing Networks

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***Abstract*—In this paper, we develop a mixed-integer programming model for integrated partner selection and scheduling in an Internet-enabled dynamic manufacturing network environment. We assume that all stakeholders in the supply chain (SC) share information on their capacities, schedules, and cost structures. Based on this information, the model addresses the issue of partner selection and SC synchronization for profit maximization, while considering various manufacturing and logistics constraints. Furthermore, we study the dynamic configuration of the SC and its performance with respect to different buyer locations, different order patterns, and the utilization of transshipment hubs. The model is solved using optimization tools from ILOG, located in Paris, France, and Mountain View, CA.**

***Index Terms*—Internet-enabled supply chains, mixed-integer linear program, partner selection, supply chain design, supply chain planning and scheduling.**

I. Notation

For development of a mathematical model for the above scenario, the following notations were used.

A. Identifiers

r	Component type identifier.
R	Number of component types.
v	Component supplier identifier.
V	Number of component suppliers.
i	Subassembly type identifier.
I	Number of subassembly types.
j	Subassembly supplier identifier.
J	Number of subassembly suppliers.
k	Contract Manufacturer identifier.
K	Number of Contract Manufacturers.
m	Buyer identifier.
M	Number of Buyers.
l	Brand identifier.
L	Number of Brands.
l	Shipping Package identifier.
L	Number of Shipping Packages.
d	Transportation Mode (Sea, Air, etc.) identifier.
D	Number of Transportation Modes.
t	Time Period identifier.
T	Total time horizon of the model.

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B. Parameters

$PCap_{abt}$ Maximum production capacity for component/subassembly/brand of type a offered by Component Supplier/Subassembly Supplier/Contract Manufacturer b in time period t. It is assumed that the offered capacity is the total available capacity with the producer, which already takes into consideration other commitments that the producer may have made on his capacity. Also the capacity is specific to the capacity of the manufacturing line for individual models and products.

PC_{ab} Per-unit production cost for component/subassembly/brand of type a produced by Component Supplier/Subassembly Supplier/Contract Manufacturer b.

PFC_{ab} Fixed cost of production setup or ordering for component/subassembly/brand of type a produced at Component Supplier/Subassembly Supplier/Contract Manufacturer b.

$TCap_{abcdt}$ Maximum transportation capacity for shipment of component/subassembly/brand of type a from Component Supplier/Subassembly Supplier/Contract Manufacturer b to its customer c in time period t through mode d. The transportation capacity depends on the schedules of the logistics provider. For days/time periods when the flights/shipments are scheduled, the capacity is nonzero, whereas for days/time periods when the service is not available, the capacity is taken to be zero.

TC_{abcdt} Per-unit transportation cost for shipment of component/subassembly/brand of type a from Component Supplier/Subassembly Supplier/Contract Manufacturer b to its customer c in time period t through mode d.

TFC_{abcd} Fixed cost for procuring capacity for shipment of component/subassembly/brand of type a from Component Supplier/Subassembly Supplier/Contract Manufacturer b to its customer c in time period t through mode d.

WC_{ab} Per-unit inventory cost incurred for component/subassembly/brand of type a in the possession of Component Supplier/Subassembly Supplier/Contract Manufacturer b.

TL_{bcd} Transportation lead time for shipment from Component Supplier/Subassembly Contract Manufacturer b to its customer c.

P_{ab} Revenue per unit of model type a sold to Buyer b.

BD_{abt} Quantity for model type a required by Buyer b in time period t.
BSL_{ab} Service Level for type a required by Buyer b.
LSC_{ab} Cost incurred because of a lost sale of Brand a to Buyer b.
R_{ab} Units of component type a required in the production of one unit of subassembly b.
M_{ab} Units of subassembly type a required in the production of one unit of model b.

C. Variables

Q_{abt} Quantity produced for component/subassembly/brand a by Component Supplier/Subassembly Supplier/Contract Manufacturer b in time period t.
I_{abt} Inventory of component/subassembly/brand a with Component Supplier/Subassembly Supplier/Contract Manufacturer b in time period t.
S_{abcdt} Quantity shipped of component/subassembly/brand of type a from Component Supplier/Subassembly Supplier/Contract Manufacturer b to its customer c through transportation mode d in time period t.
S'_{abcdt} Quantity received of component/subassembly of type a from Component Supplier/Subassembly Supplier/Contract Manufacturer b to its customer c in time period t through transportation mode d.
F_{abt} Fixed cost of ordering/setup applies for production of component/subassembly/brand of type a by Component Supplier/Subassembly Supplier/Contract Manufacturer b in time period t. Takes on binary values $\{0, 1\}$.
F_{abcdt} Fixed cost associated with shipping component/subassembly/brand of type a from Component Supplier/Subassembly Supplier/Contract Manufacturer b to its customer c through transportation mode d in time period t applies. Takes on binary values $\{0, 1\}$.
BS_{abt} Quantity sold of Brand type a to Buyer b in time period t.

II. Introduction

In RECENT years, the business world has increasingly been focusing on building core competencies and outsourcing to improve efficiency and minimize risk. In order to enhance their competitiveness, companies no longer take ownership of all the assets and processes needed in delivering value to the customer. Instead, they focus on their core competencies and partner with companies possessing complementary strengths.

This has given rise to the formation of supply chain (SC) networks and the emergence of intermediaries such as third-party logistics providers, contract manufacturers, and electronic marketplaces in almost all industries. An SC network is defined as a collection of independent companies, possessing complementary skills and integrated with streamlined material, information, and financial flows that work together to meet market demand. In fact, competition nowadays is not between individual companies but between SC networks, so much so that unless companies align themselves with particular SC networks they face the prospect of having no business and being isolated. On the other hand, if companies participate in a SC network, they can enjoy the benefits accruing from increased sales and market share of their SC network.

Many of these networks are controlled by original equipment manufacturers (OEMs) or channel masters, who own the brand of the end product and select other manufacturing and logistics partners in the SC network based on characteristics such as the requirements of the market, the capabilities, efficiency, reliability, and location of the partner, and the total cost of order fulfillment. It is no longer enough to merely be the best-of-breed manufacturer or contract manufacturer, it is also critical to partner with best-of-breed companies for other SC functions such as component manufacturing, logistics, maintenance, testing, etc.

The cornerstone of highly competitive and efficient SC networks is collaboration, including the sharing of proprietary up-to-date operational data such as production schedules, operational costs, and inventory levels. The Internet, and in particular the emergence of web-based electronic marketplaces, has fuelled this trend by providing an inexpensive, secure, and pervasive medium for information transfer between businesses. Channel masters, contract manufacturers, third- and fourth-party logistics service providers, electronic marketplaces, and other SC stakeholders are using the platform of the Internet and the information obtained through collaborative arrangements to improve their operations and provide better service levels to their customers. However, the establishment of such collaborative agreements requires significant effort in changing the mindset of companies, from that of promoting traditional adversarial relationships between companies to one establishing an environment of trust and openness between them. Also, the issue relating to sharing of network profits among collaborating enterprises needs to be resolved separately, as has been done by airlines, telecom, and utility network operators.

Once companies are willing to collaborate, the relative ease of forming partnerships and collaborating through the Internet allows the formation of fluid and dynamic SC networks based upon virtual integration between partners. The configuration of such a dynamic SC network is responsive to the needs of the market and the constraints of the SC, to the extent that the selection of partners for fulfilling an order can be entirely different from one order to the next [1], [2].

Such SC networks are common in a number of industries and particularly in the high tech, automotive, and defense manufacturing industries. An Internet-based SC network has recently been set up by Hewlett-Packard (HP), a large PC manufacturer. It has established a private collaborative marketplace to share information amongst all the participants in its SC [3]. HP posts its demand on the system for its partners to see, and the partners, in turn, post their production plans and schedules for HP to see and plan upon. HP plays the coordinating role in the center of this system, keeping the supply and demand in balance.

A. Partner Selection Problem

Given this scenario, in the formation of an effective dynamic SC network, the selection of partners, in each tier of the SC, for fulfillment of each and every order is extremely important. This requires the development of optimization models and solutions, for multitier partner selection and integrated planning, making full use of the information available on capacities, inventories, lead times, production schedules, and cost.

Specifically, with regards to global OEMs, channel masters, and private marketplace managers, the partner selection problem translates into the systematic selection of logistics providers, contract manufacturers, component suppliers, assembly plants, and transshipment facilities, such that the total profit from servicing the needs of selected profitable buyers is maximized, while taking into consideration the capacity availability of partners and other SC constraints. Similarly, the partner selection problem in the case of manufacturers and lead logistics providers relates to the choice of suppliers and other intermediaries in their chain that allow them to maximize their profits.

Our thesis here is that partner selection should be dependent on the buyer's location and should maximize profit by identifying profitable buyers and minimizing the total cost of manufacturing and logistics across multiple tiers of the SC. The decision to partner with particular companies in a dynamic SC network for a particular order relates to the partner selection problem, which we address here.

B. Literature Survey

There is a significant amount of literature existing on component supplier selection, by manufacturers, in the operations research and management science literature. Their scope, however, is limited to finding the partners in a two-level (manufacturer-supplier) SC. Weber and Current [4] discuss a multicriteria analysis for vendor selection. They develop a model for minimizing total cost, late deliveries, and supply rejection, given the infrastructure constraints and constraints imposed by the company's policy. Pan [5] presents a simple linear programming (LP) model that can be used to determine optimal order quantities among suppliers subject to specific quality, lead time, and service requirements from the buyer. Chaudhry *et al.*, [6] consider the problem of vendor selection where buyers need to choose order quantities with vendors in a multisourcing network. Narasimhan and Stoynoff [7] present a model for optimizing aggregate procurement allocation, keeping in mind contract requirements, supplier capacities, and economic manufacturing quantity-related constraints. The interested reader might find [8] useful for a comprehensive classification of publications on vendor selection criteria.

In the SC management literature, Arntzen *et al.* [9] describe a global SC management model that was implemented at Digital Equipment Corporation. The model incorporates capacity constraints, import taxes, fixed charges, transportation constraints, etc., and determines the locations for production and distribution, and the supplier network. Amours *et al.* [10] discuss the impact of information sharing in networked manufacturing, by comparing the optimal SC design for different information sharing and bidding strategies. Some researchers have focused on the production scheduling aspects of the SC. Bretthauer and Cote [11] talk about a nonlinear programming model for multiperiod capacity planning. Brucker *et al.* [12] discuss models for project scheduling in a resource-constrained manufacturing network. Gjerdrum *et al.* [13] present a mixed-integer LP (MILP) model to address a key and relevant issue relating to the sharing of profits from collaboration in a SC. Erenguc *et al.* [14] review and evaluate some of the relevant literature on production and distribution planning at each stage of the SC. Gaonkar and Viswanadham [15] present an LP-based model for collaborative SC planning in contract manufacturing networks and employ the model to quantify the benefits of information sharing in such networks. Vidal and Goetschalckx [16] present an extensive review of strategic production-distribution models in the literature. They compare the features of models presented by Geoffrion and Graves [17], Goeffrian *et al.* [18], Brown *et al.* [19], Cohen and Lee [20], Cohen *et al.* [21], Cohen and Moon [22], Arntzen *et al.* [9], and Cole [23].

C. Motivation and Contribution

Our motivation in this paper is to develop MILP mathematical programming models for some practical problems arising in private marketplaces and dynamic SC networks. In particular we wish to facilitate partner selection decisions and SC synchronization, incorporating real-world constraints of capacity limits, shipping schedules, consolidation, transshipment, etc., and in the process, build an integrated planning decision support system for channel masters, SC process owners, and electronic market participants. Our approach herein is to conduct computational experiments on a series of mathematical models and analyze and compare results from the experiments.

In terms of the contribution of our work, we attempt to do much more than the existing literature by attempting to integrate partner selection in the context of SC planning with operational synchronization. We select the SC configuration for every customer order, and additionally, provide schedules for manufacturing, assembly, and inbound and outbound transportation within the SC. Hence, our first and primary contribution in this paper is in the development of models for partner selection in complex multitier SC networks. Secondly, our model provides an integrated strategic and operational-level SC planning tool which specifically incorporates logistics features such as fixed schedules, transshipment hubs, and merge-in-transit, which have so far never been considered in the literature. And finally, the model also formalizes decision making for SC synchronization in Internet-enabled SC networks.

We consider a multitier SC with buyers, brand manufacturers, subassembly suppliers, component suppliers, and logistics service providers. A dominant channel master coordinates all their activities. The model, developed in this paper for the channel master's decision support system, determines the optimal order quantities to be allocated to each of the manufacturers, suppliers, and logistics service providers, and generates the produc-

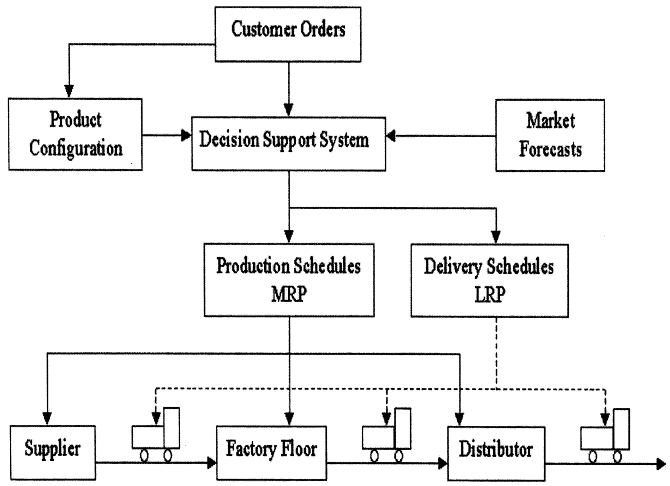

Fig. 1. Decision support system for integrated planning and scheduling.

TABLE I
KEY FEATURES OF THE MIXED-INTEGER LP MODEL FOR AN INTEGRATED SUPPLY CHAIN

Supply Chain Information Shared	Decisions to be Made
1. Available-to-Promise Manufacturing Capacity for each Suppliers.	1. Allocation of procurement quantities amongst multiple suppliers.
2. Fixed Airline Schedules.	2. Determination of least-total-cost lot sizes for procurement.
3. Transportation Lead-time.	3. Determination of multiple plant schedules.
4. Transshipment Hub and Merge-in-Transit.	4. Determination of inventory holding in each time period at each location.
5. Complex product structure with multiple components, sub-assemblies, brands.	5. Determination of mode of transportation for logistics.
6. Fixed and Variable costs of ordering, production and transportation.	6. Allocation of shipment quantities between various logistics providers.
7. Customer Service Level.	
8. Inventory costs at multiple levels.	
9. Transportation and Production costs.	

tion and delivery schedules for each of them as shown in Fig. 1. A transshipment hub is also modeled, and a consequential rationalization of the supplier base is noted.

D. Outline of the Paper

In the remaining four sections of this paper, we develop a MILP model for integrated partner selection and scheduling in a web-enabled SC network environment. We begin by describing, in Section III, the problem we wish to address and formulating a MILP model for integrated partner selection and scheduling. Our model considers various practical aspects of a SC. In Table I is a listing of some of the key features of this model.

In Section IV, we present and discuss some of the results from our experiments under the section on computational results. We study the partner selection problem in the context of global manufacturing, followed by an analysis of dynamic configurations of SC networks, a study of the impact of transshipment hubs on SC networks, and an analysis of SC costs under various market conditions. And finally we conclude, in Section V, by presenting some of our observations in the field of dynamic SC networks.

III. PROBLEM FORMULATION

A. Problem Description

We assume that there are a number of component suppliers, subassembly manufacturers, brand manufacturers, and logistics service providers in different geographical locations. They all share information on their production schedules, capacity, cost, quality, etc., with the channel master. We also assume that there are a number of buyers with orders for a range of finished goods. These orders can be fulfilled by different sets of manufacturers and suppliers at different costs and in different lead times with the support of the logistics service providers. The logistics service providers have their own costs, capacity constraints, and fixed shipping schedules. It is also possible to route some materials through transshipment hubs, where materials bound for the same destination can be packaged together for shipment, usually at a much lower overall cost. Information is also available on the ordering costs for procuring goods from the supplier and the logistics capacity from the logistics service provider. With access to such detailed operational information on all the participants in an Internet-enabled SC, the challenge for the channel master is how best to maximize its revenue and meet the demands of the buyers, using a combination of sellers and logistics providers with minimal operational cost. In particular, a collaborative approach in SC management and coordination, such as collaborative transportation management [24], is required to form an effective and efficient value web. The Internet has enabled economically viable real-time SC coordination in dynamic manufacturing networks as shown in Fig. 2.

The challenge for a channel master is the selection of suppliers, manufacturers, assemblers, and logistics service providers who can collectively meet the deadlines of the buyers and maximize the profit of the network. Apart from incorporating the capacity constraints in the SC decisions, production activities need to be synchronized with the schedules of the logistics service providers, so that items can be ready for pickup in a just-in-time manner, instead of having to wait in inventory. There can be significant cost savings through this exercise, especially in terms of synchronization of activities leading to reduced inventory levels.

B. Mixed-Integer Programming (MIP) Model

We now develop an MIP model for a dynamic manufacturing network. We assume that the channel master with access to operational information on the entire SC employs the model to select partners and synchronize the material flow through the network. The objective of the model is to maximize the profit earned by the network subject to various capacity, production, and logistics schedules and flow-balancing constraints.

1) Objective Function: The profit was calculated, as given in (1) at the bottom of the next page, as the sum of the revenue made from sales to the buyers, less the costs incurred in the operation of the SC network. The first term in the equation represents

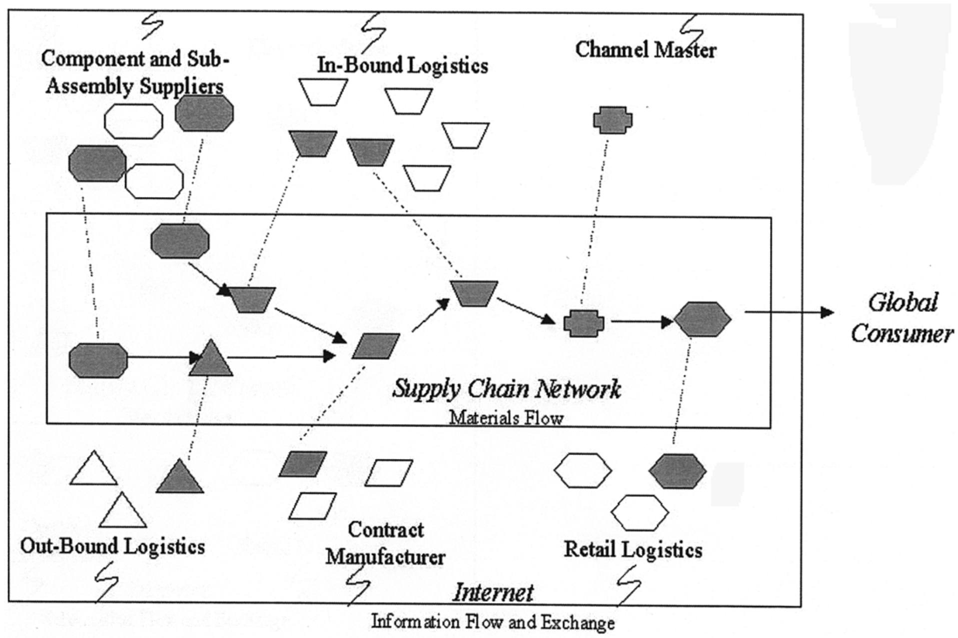

Fig. 2. SC configuration and coordination between a set of partners using the Internet.

the revenue, followed by fixed and variable costs for production and transportation, respectively, and inventory holding costs and the cost of lost sales.

There are various capacity constraints on the component suppliers, subassembly suppliers, contract manufacturers, and the logistics service providers servicing the buyer that make the solution nontrivial.

2) Component Supplier Constraints: The component suppliers cannot produce more than their maximum production capacity. The quantity produced will be less than the maximum

$$
\begin{aligned}
\text{MaxPROFIT} = &\sum_{l=1}^{L}\sum_{m=1}^{M}\sum_{t=1}^{T} P_{lm}BS_{lmt} \\
&- \left[\sum_{r=1}^{R}\sum_{v=1}^{V}\sum_{t=1}^{T}(PFC_{rv}F_{rvt} + PC_{rv}Q_{rvt}) + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T}(PFC_{ij}F_{ijt} + PC_{ij}Q_{ijt})\right. \\
&\qquad \left. + \sum_{l=1}^{L}\sum_{k=1}^{K}\sum_{t=1}^{T}(PFC_{lk}F_{lkt} + PC_{lk}Q_{lkt})\right] \\
&- \left[\sum_{r=1}^{R}\sum_{v=1}^{V}\sum_{j=1}^{J}\sum_{d=1}^{D}\sum_{t=1}^{T}(TFC_{rvjd}F_{rvjdt} + TC_{rvjd}S_{rvjdt})\right. \\
&\qquad + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{d=1}^{D}\sum_{t=1}^{T}(TFC_{ijkd}F_{ijkdt} + TC_{ijkd}S_{ijkdt}) \\
&\qquad \left. + \sum_{l=1}^{L}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{d=1}^{D}\sum_{t=1}^{T}(TFC_{lkmd}F_{lkmdt} + TC_{lkmd}S_{lkmdt})\right] \\
&- \left[\sum_{i=1}^{T}\left(\sum_{r=1}^{R}\sum_{v=1}^{V} WC_{rv}I_{rvt} + \sum_{r=1}^{R}\sum_{j=1}^{J} WC_{rj}I_{rjt} + \sum_{i=1}^{I}\sum_{j=1}^{J} WC_{ij}I_{ijt}\right.\right. \\
&\qquad \left.\left. + \sum_{i=1}^{I}\sum_{k=1}^{K} WC_{ik}I_{ikt} + \sum_{l=1}^{L}\sum_{k=1}^{K} WC_{lk}I_{lkt} + \sum_{l=1}^{L}\sum_{m=1}^{M} WC_{lm}I_{lmt}\right)\right] \\
&- \left[\sum_{l=1}^{L}\sum_{m=1}^{M}\sum_{t=1}^{T}(BD_{lmt} - BS_{lmt})\, LSC_{lmt}\right]
\end{aligned} \tag{1}
$$

capacity when fixed cost of production is incurred and production is undertaken or else will be zero. Conversely, if the quantity produced is zero fixed cost of production will not apply. Hence

$$Q_{rvt} \le PCap_{rvt}F_{rvt} \text{ and } Q_{rvt} \ge F_{rvt}, \quad \text{for all } r \in R,\ v \in V \,\&\, t \in T. \tag{2}$$

The components produced are held at the component supplier's end until they are shipped off to the subassembly manufacturers. The production of new components adds to the inventory held by the component supplier at the end of each time, while the products sold and shipped to the subassembly suppliers in each time period reduces the component supplier's inventory

$$I_{rv(t-1)} + Q_{rvt} = \sum_{j=1}^{J}\sum_{d=1}^{D} S_{rvjdt} + I_{rvt}, \quad \text{for all } r \in R,\ v \in V \,\&\, t \in T. \tag{3}$$

However, the quantity that can be transported in a single period is constrained by the maximum capacity of the transportation infrastructure. Considering our scenario with fixed shipping schedules, in time periods when the service is available, the transportation capacity is nonzero. However, for time periods where particular flights or shipments are not scheduled, the transportation capacity is zero. Hence, the transportation of the component types from the component suppliers to the subassembly suppliers' sites are bound by the constraint given below. Once more, the fixed cost of shipping is modeled through a binary variable representing whether shipment is undertaken or not.

$$S_{rvjdt} \le TCap_{rvjdt}F_{rvjdt} \text{ and } S_{rvjdt} \ge F_{rvjdt}, \quad \text{for all } r \in R,\ v \in V,\ j \in J,\ d \in D \,\&\, t \in T. \tag{4}$$

Additionally, if the production level of a particular component has been at zero in all the previous time periods for a component supplier, the shipments of that particular component for the component supplier will all be zero. This constraint was found to be useful in providing better bounds for the solution

$$\sum_{w=1}^{t} F_{rvw} \ge F_{rvjdt}, \quad \text{for all } r \in R,\ v \in V,\ j \in J,\ d \in D \,\&\, t \in T. \tag{5}$$

3) Subassembly Supplier Constraints: The shipped components reach the subassembly suppliers after a certain amount of time, which relates to the transportation lead time. The SC model we assume is such that the material is collected by the transportation system from the output buffer of one stage and delivered to the input buffer of the subsequent stage, after a designated time interval equivalent to the transportation lead time. Hence, transportation lead time between the component suppliers and subassembly suppliers is modeled by equating the outbound shipment from the component supplier to the inbound shipment at the subassembly supplier, in a subsequent time period

$$S'_{rvjdt} = S_{rvjd(t-TL_{vjd})}, \quad \text{for all } r \in R,\ v \in V,\ j \in J,\ d \in D \,\&\, t \in T. \tag{6}$$

Once the components reach the subassembly supplier, it adds to the subassembly supplier's inventory, which is then consumed by the production process. However, before the production process can start and the component type can be consumed, the subassembly supplier will need to check adequate availability of all components that will be used in the assembly-part production process. This imposes the following constraint on the component availability and the assembly-part production:

$$I_{rj(t-1)} \ge \sum_{i=1}^{I} R_{ir}Q_{ijt}, \qquad \text{for all } r \in R,\ j \in J,\ t \in T. \tag{7}$$

However, once the production process begins, the inventory drops. The inventory status for component types with the subassembly supplier can be determined as given below

$$I_{rj(t-1)} + \sum_{v=1}^{V}\sum_{d=1}^{D} S'_{rvjdt} = \sum_{i=1}^{I} R_{ir}Q_{ijt} + I_{rjt}, \quad \text{for all } r \in R,\ j \in J \,\&\, t \in T. \tag{8}$$

The capacity constraints and the inventory constraints that apply to the component suppliers apply to the subassembly suppliers as well.

The maximum production of subassemblies is constrained by the production capacity of the subassembly suppliers

$$Q_{ijt} \le PCap_{ijt}F_{ijt} \text{ and } Q_{ijt} \ge F_{ijt}, \quad \text{for all } i \in I,\ j \in J \,\&\, t \in T. \tag{9}$$

The inventory of subassemblies at the subassembly supplier's end increases at the end of each period by the quantity produced, and decreases by the amount of subassembly shipped out to the contract manufacturer and the transshipment hub, in that time period

$$I_{ij(t-1)} + Q_{ijt} = \sum_{k=1}^{K}\sum_{d=1}^{D} S_{ijkdt} + I_{ijt}, \quad \text{for all } i \in I,\ j \in J \,\&\, t \in T. \tag{10}$$

The quantity of assembly parts that can be shipped is constrained by the capacity of the transportation infrastructure

$$S_{ijkdt} \le TCap_{ijkdt}F_{ijkdt} \text{ and } S_{ijkdt} \ge F_{ijkdt}, \quad \text{for all } i \in I,\ j \in J,\ k \in K,\ d \in D \,\&\, t \in T. \tag{11}$$

In case a subassembly supplier has previously not undertaken production of an assembly part, the shipments of that assembly part from the subassembly supplier will be zero

$$\sum_{w=1}^{t} F_{ijw} \ge F_{ijkdt}, \quad \text{for all } i \in I,\ j \in J,\ k \in K,\ d \in D \,\&\, t \in T. \tag{12}$$

4) Contract Manufacturer Constraints: The shipped assembly parts reach the contract manufacturer after a certain amount of time

$$S'_{ijkdt} = S_{ijkd(t-TL_{jkd})}, \quad \text{for all } i \in I,\ j \in J,\ k \in K,\ d \in D \,\&\, t \in T. \tag{13}$$

The shipped assembly parts will be stored at the contract manufacturer. The contract manufacturer will produce a variety of brands, which will use up the inventory of the subassemblies in the process. However, only in the case of sufficient availability of all the needed subassemblies will production of the brands take place

$$I_{ik(t-1)} \geq \sum_{l=1}^{L} M_{li} Q_{lkt}, \qquad \text{for all } i \in I,\ k \in K \ \&\ t \in T. \tag{14}$$

As regards the inventory levels of subassemblies at the contract manufacturer, incoming stocks will add to the inventory and subassembly stocks will be used up in the production of the various brand types. The inventory status for subassemblies at the contract manufacturer can be determined as given below

$$I_{ik(t-1)} + \sum_{j=1}^{J}\sum_{d=1}^{D} S'_{ijkdt} = \sum_{l=1}^{L} M_{li} Q_{lkt} + I_{ikt}, \quad \text{for all } i \in I,\ k \in K \ \&\ t \in T. \tag{15}$$

The manufacturer cannot produce the different brand types in a quantity more than its maximum production capacity. Hence

$$Q_{lkt} \leq PCap_{lkt} F_{lkt} \text{ and } Q_{lkt} \geq F_{lkt}, \quad \text{for all } l \in L,\ k \in K \ \&\ t \in T. \tag{16}$$

The manufactured units of the brands are stored at the manufacturer awaiting delivery to the buyer. The inventory level of the brands obeys the following flow constraint

$$I_{lk(t-1)} + Q_{lkt} = \sum_{m=1}^{M}\sum_{d=1}^{D} S_{lkmdt} + I_{lkt}, \quad \text{for all } l \in L,\ k \in K \ \&\ t \in T. \tag{17}$$

The transportation capacity constraint for the movement of the brands from the contract manufacturer to the buyer's location will be governed by the below transportation capacity constraint

$$S_{lkmdt} \leq TCap_{lkmdt} F_{lkmdt} \text{ and } S_{lkmdt} \geq F_{lkmdt}, \quad \text{for all } l \in L,\ k \in K,\ m \in M,\ d \in D \ \&\ t \in T. \tag{18}$$

Contract manufacturers that have not produced a particular type of brand in prior periods will not be able to ship it

$$\sum_{w=1}^{t} F_{lkw} \geq F_{lkmdt}, \quad \text{for all } l \in L,\ k \in K,\ m \in M,\ d \in D \ \&\ t \in T. \tag{19}$$

5) Buyer Constraints: The brands reach the buyer after a certain transportation lead time

$$S'_{lkmdt} = S_{lkmd(t-TL_{kmd})}, \quad \text{for all } l \in L,\ k \in K,\ m \in M,\ d \in D \ \&\ t \in T. \tag{20}$$

The shipment of the brands is stored at a location near the buyer and is sold to the buyer based on its demand requirements and the service level promised to the buyer

$$I_{lm(t-1)} + \sum_{k=1}^{K}\sum_{d=1}^{D} S'_{lkmdt} = I_{lmt} + BS_{lmt}, \quad \text{for all } i \in I,\ j \in J,\ k \in K,\ d \in D \ \&\ t \in T. \tag{21}$$

Finally, quantity sold to the buyer in each time period cannot be more than the demand or less than the quantity committed to by the service level agreement

$$BSL_{lm} BD_{lmt} \leq BS_{lmt} \leq BD_{lmt}, \quad \text{for all } l \in L,\ m \in M \ \&\ t \in T. \tag{22}$$

This model presented above provides a generic framework to study various SC concepts. With respect to international trade logistics, the cost of customs duties and tariffs can be included in the fixed and variable cost components of cross-border transportation. This model can also be adapted to quantify the savings from information sharing as presented in [15]. Even though it is not done here, this model can also be used as a practical tool for simultaneously managing SC activities for multiple generations of product lifecycles.

C. Other Modeling Issues: Modeling a Transshipment Hub

A variation of the SC network developed above was considered by modeling transshipment hubs between the subassembly suppliers and the contract manufacturers. The role of the transshipment hubs was to provide a facility where different components bound to the same destinations could be packaged and sent together through lower cost and possibly higher volume transportation modes. Subassemblies from the subassembly suppliers arrive at the transshipment hub. They then wait at the transshipment hub to be packaged together with other items destined to the same location or, alternately, if there are enough subassemblies to ship, or if the subassemblies are urgently needed, the subassemblies are dispatched to the contract manufacturers immediately. Holding costs are incurred for the time the subassemblies are warehoused in the transshipment hub.

Hence, the transshipment hub is modeled as a facility with an inventory of inbound subassemblies and outbound shipping packages. The set of constraints for the transshipment hub are similar to the constraints for the subassembly supplier and the contract manufacturer, with a set of constraints for inbound and outbound inventory balancing, and a production constraint representing the activity of packaging different types of subassemblies into one shipping package. Additionally, terms need to be added to the outbound inventory-flow-balancing constraint for the subassembly suppliers, highlighting the additional shipment option to the transshipment hub. Similarly, there are additional terms in the inbound inventory-flow-balancing constraint for the contract manufacturers, representing the fact that packages from the transshipment hub add to all the inbound inventories, related

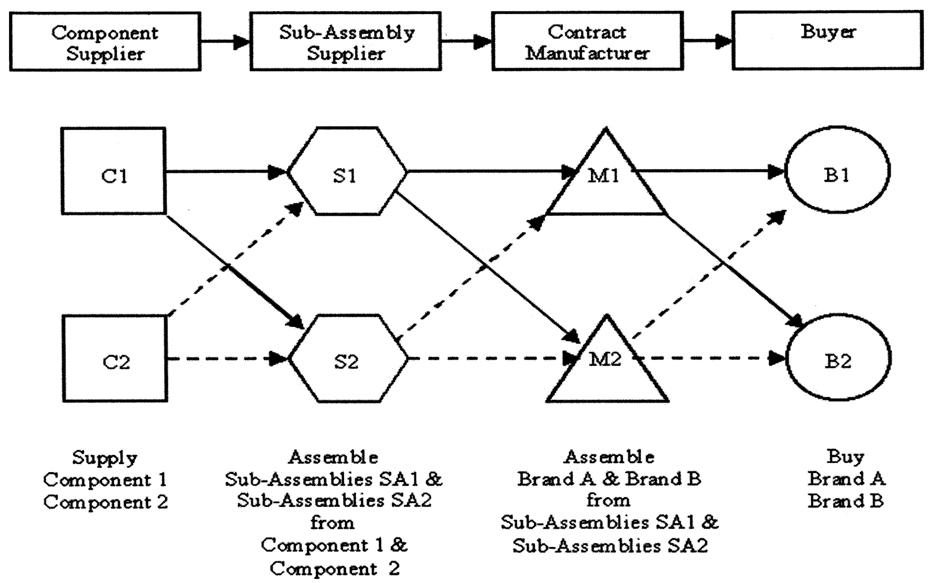

Fig. 3. Two-tier SC.

to the subassemblies carried within the shipping package. A detailed listing of the additional constraints for a transshipment hub is given in the Appendix.

D. Solving the Model in ILOG's OPL Studio

The MILP model developed herein can be solved using any of the commonly available mixed-integer solvers. For our analysis, we employed the CPLEX branch-and-bound integer solver, available in the commercial optimization suite OPL Studio, developed by ILOG, located in Paris, France, and Mountain View, CA.

ILOG provides a very comprehensive library of optimization algorithms implemented in C++. These algorithms can be used for the solution of a varied number of large-scale linear, integer, and constraint programming models. ILOG also incorporates a set of modeling concepts, such as activities and resources, which are very useful in the solution of scheduling and allocation problems. The OPL Studio modeling environment from ILOG utilizes the optimization programming language (OPL) for problem modeling. User-defined search strategies for each model can be specified in order to reduce the computational power required for the solution.

The above MILP model was developed in OPL Studio and solved for a scenario with three component suppliers, five subassembly suppliers supplying two different product types to three contract manufacturers, who sell two different model types to two buyers. Not all contract manufacturers manufacture all models or all suppliers supply all product types. The time horizon for the model was taken as 24 periods. The modes of transportation between the facilities were considered to be air $(d = 1)$ and sea $(d = 2)$. Air transportation was assumed to be twice as expensive, but four times faster than sea transportation.

In some of the larger problems considered, the number of variables that were encountered were around 19 000 (including 6000 binary variables) with around 25 000 constraints. Good feasible solutions within 10%-15% of the optimum were obtained within 10-20 minutes. For the purpose of our analysis, we only considered solutions within at least 3%-5% of the optimum. At the maximum, it required around 8-10 hours for the solution to reach within this range. In some cases, we were also able to prove optimality.

IV. Computational Results

Various computational experiments were performed to study the dynamic nature of the SC network and to analyze the performance of the SC under different conditions.

A. General Observations

In the lack of any capacity constraints at the supplier's and manufacturer's facility and the availability of transportation infrastructure, the problem leads to the trivial solution where the cheapest complete link from the supplier to the buyer is chosen.

The solution of the MIP model provides a breakdown of the optimum raw material production quantity, inventory holding, and manufacturing capacity utilization for each time period at each of the partner locations. This information is key to scheduling SC activities to perform at optimal levels. Hence, the MIP model provides an integrated strategic-level partnership tool and a low-level operational synchronization and scheduling tool as well.

B. Illustrative Example on Global Manufacturing

To illustrate the supplier selection problem in global manufacturing, the following example was considered, with two buyers, two suppliers, and two manufacturers in the marketplace, as depicted in Fig. 3. The model in Fig. 3 depicts a two-tier SC network of suppliers, manufacturers, and buyers. The buyer places orders for finished goods, which are assembled and delivered by the manufacturer using the subassemblies procured from the suppliers. Each supplier may provide a few types of subassemblies, which the manufacturer can use to produce a range of finished goods. The supplier, in turn,

TABLE II
BUYER-RELATED DEMAND INFORMATION

Brand	Brand A	Brand B
Buyer1	50 units @ $2500 each	25 units @ $2200 each
Buyer2	60 units @ $1800 each	40 units @ $1500 each

TABLE III
MANUFACTURER-RELATED INFORMATION

	Maximum Mfg Capacity (Units per day) @ Manufacturing Cost (Per Unit)	
Mfg	Brand A	Brand B
Mfg1	70 units @ $15 each	30 units @ $100 each
Mfg2	40 units @ $20 each	40 units @ $125 each

TABLE IV
SUBASSEMBLY SUPPLIER-RELATED INFORMATION

	Maximum Sub-Assembly Production Capacity (Units per day) @ Production Cost (Per Unit)	
Product Type	SA 1	SA 2
SASup1	70 units @ $10 each	80 units @ $300 each
SASup2	105 units @ $15 each	100 units @ $250 each

TABLE V
COMPONENT SUPPLIER-RELATED INFORMATION

	Maximum Component Production Capacity (Units per day) @ Production Cost (Per Unit)	
Product Type	Comp. 1	Comp. 2
CSup1	180 units @ $8 each	190 units @ $15 each
CSup2	210 units @ $7 each	170 units @ $20 each

TABLE VI
THIRD-PARTY LOGISTICS-RELATED INFORMATION

	Link Capacity (Units per day) @ Transportation Cost (Per Unit)	
	Comp. 1	Comp. 2
C-S1 SA-S1	120 units @ $25 each	90 units @ $30 each
C-S1 SA-S2	130 units @ $30 each	100 units @ $30 each
C-S2 SA-S1	150 units @ $80 each	140 units @ $100 each
C-S2 SA-S2	110 units @ $90 each	160 units @ $110 each
	SA 1	SA 2
SA-S1 M1	100 units @ $100 each	100 units @ $70 each
SA-S1 M2	80 units @ $80 each	70 units @ $60 each
SA-S2 M1	110 units @ $20 each	150 units @ $30 each
SA-S2 M2	120 units @ $30 each	125 units @ $40 each
	Brand A	Brand B
M1 B1	70 units @ $100 each	110 units @ $90 each
M1 B2	50 units @ $80 each	60 units @ $70 each
M2 B1	60 units @ $70 each	50 units @ $60 each
M2 B2	100 units @ $95 each	120 units @ $100 each

produces the subassemblies from a set of components procured from the component suppliers. The physical movement of goods between each of the participants is taken care of by one of the stakeholders in the transaction, and hence, is not shown separately.

For illustrative purposes, let us consider an example where both the Buyers (Buyer1 in Europe and Buyer2 in Asia) order two brands of finished products (Brand A and Brand B) in different quantities. These finished products are available from two Contract Manufacturers (OEMs) (Mfg1 in Asia and Mfg2 in the U.S.). Subassembly suppliers (SASup1 in Latin America and SASup2 in Asia) provide two kinds of subassemblies, SA1 and SA2, and one unit of each is used in the manufacturing of the finished products. Both subassemblies, in turn, are manufactured from one unit each of Component 1 and Component 2, which are procured from component suppliers (CSup1 and CSup2 in Asia). Information on the capacities and prices of each of the buyers, manufacturers, subassembly, and component suppliers is readily available in the electronic marketplace. The objective is to select the suppliers and contract manufacturers and to determine the quantity to be ordered from each of them, in order to meet all the buyer orders.

The information available in the marketplace at a given moment in time (as against multiperiod models) is given in Tables II–VI.

It is assumed that each unit of the finished good will require one unit of SA1 and one unit of SA2. Subassemblies SA1 and SA2 will, in turn, require one unit of Component 1 and one unit of Component 2 each. Furthermore, the lead time for transportation between the various sites is zero. It is also assumed that the various participants in the electronic marketplace have been prequalified with regards to their quality and credit rating.

The best possible configuration in this situation, leading to a net profit of $260,000, can be obtained as given in Fig. 4.

For buyers in Asia, the finished product is manufactured in Asia from the subassemblies procured from within the region itself. Similarly, orders from Europe are fulfilled through the U.S. manufacturer. This configuration maximizes the SC's profitability while fulfilling all the orders.

C. Dynamic SC Network Configuration

In order to verify the dynamic nature of the model that was developed in earlier sections, the model was solved for orders placed by each buyer, and the SC configuration for both cases were observed and compared.

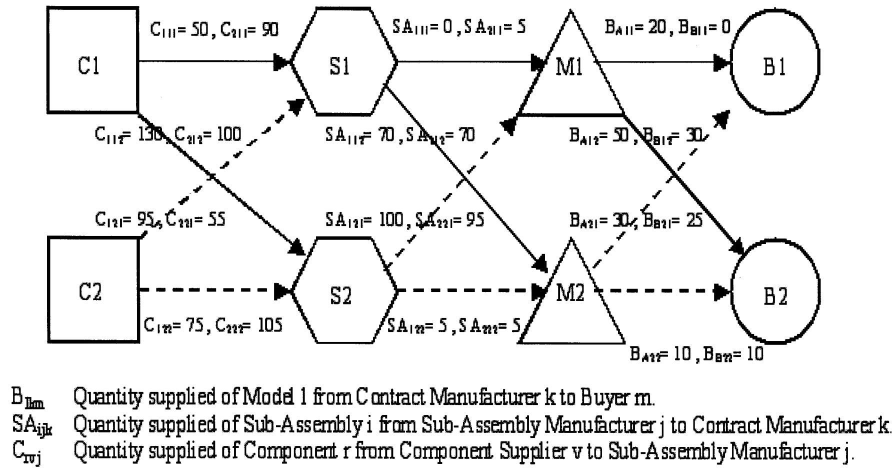

Fig. 4. Dynamic manufacturing network configuration for example 1.

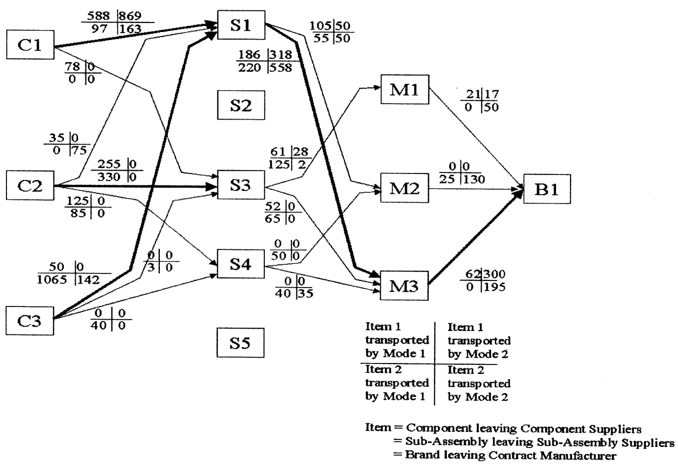

Fig. 5. Configuration to meet Buyer1 demand.

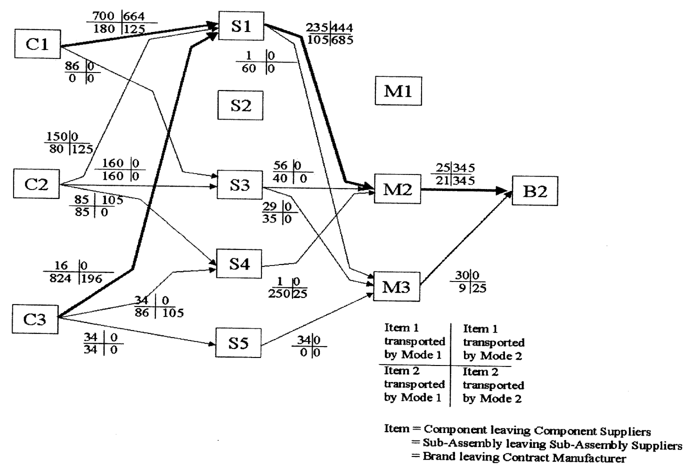

Fig. 6. Configuration to meet Buyer2 demand.

It was assumed that each buyer required 25 units each of both brands in each time period from periods 9 to 24, resulting in a total demand of 400 units for each brand over the entire time horizon. The service level required was 90%, meaning that the SC had to meet at least 90% of the demand for each brand in each time period. The orders were to be fulfilled by a manufacturing network for which all the costs, capacities, and schedules were known. The transportation costs at each stage were taken to be around 10%-15% of the total cost of the products, which is a fact commonly observed in many SCs. The bill of materials for the finished brands and subassemblies were also known.

The optimal SC configuration for the fulfillment of 400 units of the finished brands required by Buyer1, consolidated over the entire time horizon, is obtained as given in Fig. 5.

Buyer1 is slightly closer to contract manufacturer Mfg1 as compared to contract manufacturer Mfg3. However, the total cost of production and logistics is lower in procuring from Mfg3. This is partly due to the reason that Mfg3 has access to cheaper suppliers from subassembly supplier SASup1. Hence, Mfg3 satisfies most of the demand. However, due to capacity limitations on its supplier's end, it is not able to fulfill Buyer1's demand within its service level requirement. Therefore, it is much more profitable to satisfy the rest of the demand by engaging other contract manufacturers. Similarly, the manufacturing network configuration for the fulfillment of Buyer2's orders, with Mfg2 as the main supplier of brands to Buyer2, is shown in Fig. 6.

From the two scenarios it is noticed that, depending on where the buyer is, an appropriate contract manufacturer is selected to fulfill the order. In case the demand is more than the quantity that the contract manufacturer's SC is able to handle, the remainder of the demand will be fulfilled through other manufacturers. One of the bottlenecks in the SC that might arise is that the contract manufacturers are not able to manufacture at full capacity due to the lack of adequate subassembly and component supply from the suppliers. This inadequate supply may be due to the fact that the suppliers cannot produce any more subassemblies or components or also due to the fact that the logistics network between the suppliers and the contract manufacturer might not have adequate capacity. Consideration is also given to the schedules of the logistics service provider, so that items are produced just in time for pickup and delivery, instead of having to wait in the inventory.

Hence, the selection of appropriate suppliers and manufacturers should be dependent on the consideration of the total landed cost of the products. Also, the selection of suppliers and

TABLE VII
REVENUES AND PROFITS IN SALES MADE TO EACH OF THE THREE BUYERS

Revenues for sales	Profit from supply chain operations
Buyer 1 purchases 400 units of Brand 1@ \$80000 and Brand 2 @ \$75000	\$ 8,234,466
Buyer 2 purchases 400 units of Brand 1@ \$80000 and Brand 2 @ \$75000	\$ 9,973,733

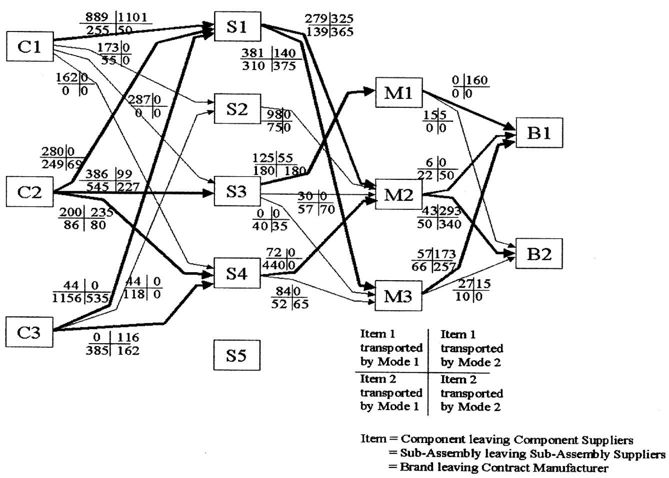

Fig. 7. Configuration for multiple buyer requirements in an electronic marketplace.

the resulting SC configuration in a virtual setup will be dependent on the needs of the buyers and their locations. Ultimately, this selection will be limited by the supply and logistics constraints within the SC.

The profit earned through the operation of the SC in both cases is presented in Table VII.

Hence, the model suggests that given a choice, it would be more profitable to accept orders from Buyer2 as compared to orders from Buyer1.

In order to simulate the multiple buyers simultaneously ordering in a marketplace, a solution was obtained for the manufacturing network configuration for the combined requests of both buyers. The solution, consolidated over the time horizon, offered by the MIP model is presented in Fig. 7. The profit from fulfilling the combined demands of both suppliers was obtained as \$16,772,552, which is about 7.88% lower compared to the sum of the profits from meeting the demands of both buyers individually. The primary reason for this drop is that in fulfilling the combined demand of the buyers, the capacities of the cheapest suppliers and logistics providers are fully utilized, and as a result, supplies need to be procured from more expensive suppliers, resulting in higher costs and lower profits.

With multiple buyers trading on the marketplaces, the SC gets more complicated, with a larger number of interconnections between the various participants in the value web. It may be noted, in line with our thesis, that under different circumstances, different partners are engaged to help fulfill the commitments of the SC network. For example, subassembly supplier SASup2 is engaged to meet the combined demands from Buyer1 and Buyer2, even though it has no role to play in the SC network when Buyer1's and Buyer2's orders are individually considered. Similarly, SASup5 supplies subassemblies for orders received from Buyer2, but is not part of the SC configuration meeting the combined orders from Buyer1 and Buyer2. This alludes to the dynamic nature of the SC model in virtual value webs.

D. Transshipment Hub in SC Networks

We also studied the impact of employing transshipment hubs within SCs on the configuration of the SC network. Transshipment hubs, as considered in this paper, model cross-docking centers and also merge-in-transit processes wherein certain goods bound to the same destination are packaged together to achieve lower costs of transportation and procurement. This also replicates the scenario where a particular supplier may be preferred during procurement for a second set of supplies, if the supplier is already supplying some other materials.

For our experiments, we assumed that the cost of transporting a shipment package from the transshipment hub was significantly lower than the sum of the costs of shipping individual subassemblies, but higher than the individual costs for transporting each subassembly. This is a realistic scenario wherein the costs of common activities are shared between the shipment processes for individual subassemblies. The SC configuration in the presence of a transshipment hub for combined orders from Buyer1 and Buyer2 is shown in Fig. 8, and results in a profit of \$19 404 153.

It may be noticed that in the presence of transshipment hubs, the number of subassembly suppliers engaged in the configuration is three and the number of contract manufacturers is two, as compared to four and three, respectively, for the same demands but without the transshipment hubs. Hence, as discussed previously, existing suppliers are preferred for procurement of additional supplies of other subassemblies. Also, the profit in working with existing suppliers results in improved profits of 15.7% compared to independently ordering the subassemblies. Hence, the argument in favor of supplier rationalization, which is a common trend in businesses nowadays.

E. Analysis of SC Costs

To identify the relative contributions of the various SC partners toward the cost of the SC, an analysis of cost distributions for various demand patterns was undertaken. Five demand patterns—steady, descending, ascending, seasonal-down, and seasonal-up—were considered, as shown in Fig. 9. Descending demand patterns occur frequently in the high-tech industry, where sales steadily decline as the innovativeness of the product wears out. Ascending demand patterns are observed when pioneering buyers satisfied with the product influence others to try it out as well. Such learning effects, or word-of-mouth effects, are particularly observed in sales of music CDs. And finally, seasonal demands are observed in various sectors wherein sales are high in one part of the year and low the rest of the year [27].

The costs for the various production, transportation, and inventory holding activities were obtained for the optimal SC configurations for all five demand patterns. The distribution of costs is plotted in Fig. 10.

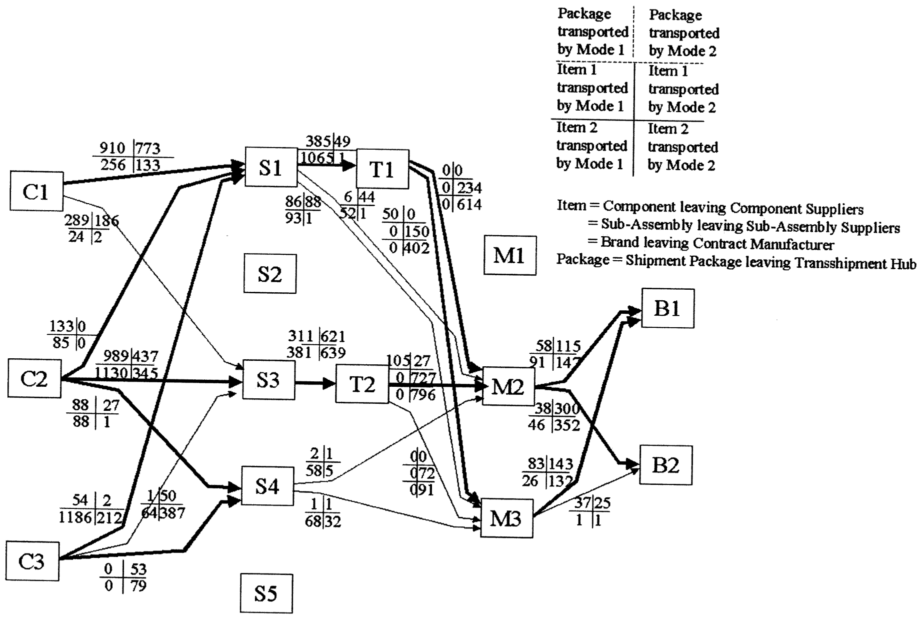

Fig. 8. Configuration for multiple buyer requirements with presence of transshipment hubs.

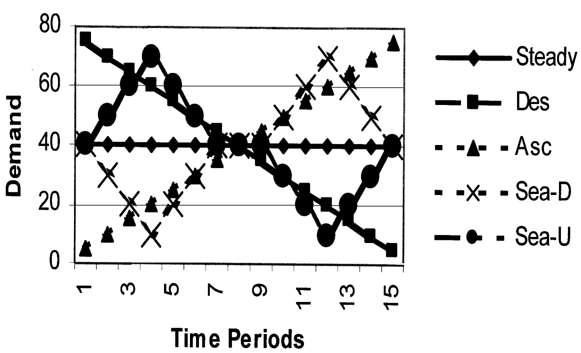

Fig. 9. Demand patterns considered for study.

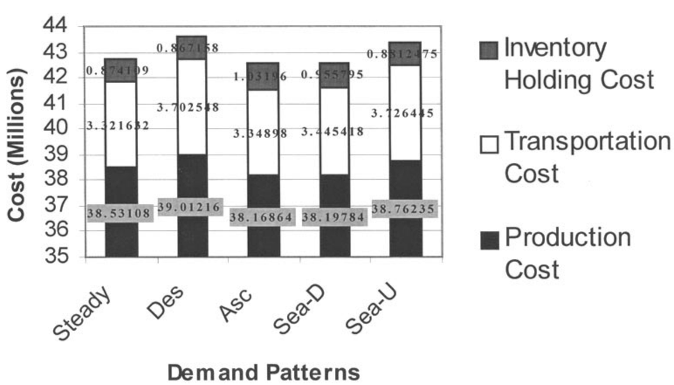

Fig. 10. Distribution of costs for the various demand patterns.

As expected, the production costs were the most significant component. In the case of decreasing demand and seasonal-up, the production costs and transportation costs are higher, compared to the other patterns, because more expensive suppliers and transportation modes have to be selected in the SC to meet the above-mean demand early on. Conversely, the production and transportation costs for ascending and seasonal-down are lower, because they have more leeway in terms of their lower demands early on to choose cheaper suppliers and transportation modes. However, their inventory holding costs are higher, since they need to carry inventory to meet the rising demands in later periods.

V. Conclusion

In this paper, we have formulated and solved the partner selection problem in global manufacturing networks. This problem is very important in the current time of globalized manufacturing, proliferating electronic marketplaces, and Internet-enabled collaborative commerce. We specifically demonstrate how integrated SC planning can be conducted using standard optimization tools. We are developing a decision support tool for use in electronic marketplaces.

Our formulation here is linear and uses an MILP model. We are planning to solve SC problems where the number of buyers and sellers are large and there are more tiers in the chain.

One finds an enormous amount of literature describing in words electronic marketplaces, e-supply chains, collaborative commerce, etc. One also comes across companies offering packaged solutions for so-called Business-to-Business (B2B) communications and material flow optimization. As academicians we always wonder about what lies within these black boxes (packaged solutions) and what can be done beyond them. Our paper provides a glimpse into what further can probably be achieved by the next generation of software solutions.

Appendix

A. Additional Constraints for Modeling a Transshipment Hub

The following changes and additions were made to the model to model the transshipment hub.

h Transshipment Hub identifier.
H Number of Transshipment Hubs.
g Shipment Package identifier.

G Number of Shipment Packages.

X_{ab} Units of subassembly type a merged into one unit of shipment package b.

SP_{abt} Quantity packaged of shipment package g at transshipment hub h in time period t.

$SPCap_{abt}$ Maximum quantity that can be packaged of shipment package g at transshipment hub h in time period t.

1) Changes to Existing Constraints: Constraint (9) changes to

$$I_{ij(t-1)} + Q_{ijt} = \sum_{k=1}^{K}\sum_{d=1}^{D} S_{ijkdt} + \sum_{h=1}^{H}\sum_{d=1}^{D} S_{ijhdt} + I_{ijt}$$
$$\text{for all } i \in I,\ \ j \in J \ \&\ t \in T.$$

Constraint (13) changes to

$$I_{ik(t-1)} + \sum_{j=1}^{J}\sum_{d=1}^{D} S_{ijkdt} + \sum_{h=1}^{H}\sum_{d=1}^{D} S_{ihkdt} + \sum_{h=1}^{H}\sum_{d=1}^{D} X_{gi} S_{ghkdt} = \sum_{l=1}^{L} M_{li} Q_{lkt} + I_{ikt}$$
$$\text{for all } i \in I,\ \ k \in K \ \&\ t \in T.$$

2) Additional Constraints:

$$S_{ijhdt} \le TCap_{ijhdt} F_{ijhdt}$$
$$\text{for all } i \in I,\ \ j \in J,\ \ h \in H,\ \ d \in D \ \&\ t \in T$$
$$S_{ijhdt} \ge F_{ijhdt}$$
$$\text{for all } i \in I,\ \ j \in J,\ \ h \in H,\ \ d \in D \ \&\ t \in T$$
$$S'_{ijhdt} = S_{ijhd(t-TL_{ijh})}$$
$$\text{for all } i \in I,\ \ j \in J,\ \ h \in H,\ \ d \in D \ \&\ t \in T$$
$$I_{ih(t-1)} + \sum_{j=1}^{J}\sum_{d=1}^{D} S'_{ijhdt} = \sum_{g=1}^{G} X_{gi} SP_{ght} + \sum_{k=1}^{K}\sum_{d=1}^{D} S_{ihkdt} + I_{iht}$$
$$\text{for all } i \in I,\ \ h \in H \ \&\ t \in T$$
$$SP_{ght} \le SPCap_{ght}$$
$$\text{for all } g \in G,\ \ h \in H \ \&\ t \in T$$
$$I_{gh(t-1)} + SP_{ght} = \sum_{k=1}^{K}\sum_{d=1}^{D} S_{ghkdt} + I_{ght}$$
$$\text{for all } g \in G,\ \ h \in H \ \&\ t \in T$$
$$S_{ihkdt} \le TCap_{ihkdt} F_{ihkdt}$$
$$\text{for all } i \in I,\ \ h \in H,\ \ k \in K,\ \ d \in D \ \&\ t \in T$$
$$S_{ihkdt} \ge F_{ihkdt}$$
$$\text{for all } i \in I,\ \ h \in H,\ \ k \in K,\ \ d \in D \ \&\ t \in T$$
$$S'_{ihkdt} = S_{ihkd(t-TL_{ihh})}$$
$$\text{for all } i \in I,\ \ h \in H,\ \ k \in K,\ \ d \in D \ \&\ t \in T$$
$$S_{ghkdt} \le TCap_{ghkdt} F_{ghkdt}$$
$$\text{for all } g \in G,\ \ h \in H,\ \ k \in K,\ \ d \in D \ \&\ t \in T$$
$$S_{ghkdt} \ge F_{ghkdt}$$
$$\text{for all } g \in G,\ \ h \in H,\ \ k \in K,\ \ d \in D \ \&\ t \in T$$
$$S'_{ghkdt} = S_{ghkd(t-TL_{ghk})}$$
$$\text{for all } g \in G,\ \ h \in H,\ \ k \in K,\ \ d \in D \ \&\ t \in T.$$

B. Market Data for Illustrative Example on Global Manufacturing

See Tables II–VI.

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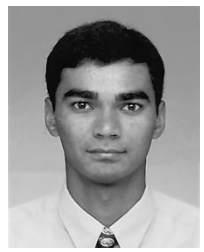

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