Global supply chain design: A literature review and critique

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Abstract:

In this paper, we review decision support models for the design of global supply chains, and assess the fit between the research literature in this area and the practical issues of global supply chain design. The classification scheme for this review is based on ongoing and emerging issues in global supply chain management and includes review dimensions for (1) decisions addressed in the model, (2) performance metrics, (3) the degree to which the model supports integrated decision processes, and (4) globalization considerations. We conclude that although most models resolve a difficult feature associated with globalization, few models address the practical global supply chain design problem in its entirety. We close the paper with recommendations for future research in global supply chain modeling that is both forward-looking and practically oriented.

Keywords: Supply chain design | Globalization | Outsourcing | Supply chain integration | International sourcing

Article:

1. Introduction

The last decades of the twentieth century witnessed a considerable expansion of supply chains into international locations, especially in the automobile, computer, and apparel industries (Taylor, 1997 and Dornier et al., 1998). This growth in globalization, and the additional management challenges it brings, has motivated both practitioner and academic interest in global supply chain management. The interest in global operations management among researchers has been documented by Prasad and Babbar (2000), who noted both a long history of attention to global operational issues, as well as an increase in the number of articles published in the leading operations management journals on this subject. Supply chain management is not just a domestic phenomenon—supply chains transcend national boundaries, imposing the challenges of globalization on managers who design supply chains for existing and new product lines.

In this paper, we review articles pertaining to global supply chain design and focus on the logistics of the supply chain, i.e., the movement of goods from the point of origin to the point of consumption (Vitasek, 2003). Fig. 1 illustrates alternative production locations for a global supply chain, depicting manufacturing activities for an end-product and for multiple tiers of components. The supply chain is arranged in tiers that represent production stages, which are organized such that the outputs from one tier are the inputs to the next. For example, a factory in an apparel supply chain that produces plastic ships to a factory that uses that material to produce zippers that are then shipped to a factory that assembles jackets. As depicted in Fig. 1, these materials, components, and end-products may be produced in company-owned or supplier facilities, in either domestic or international locations.

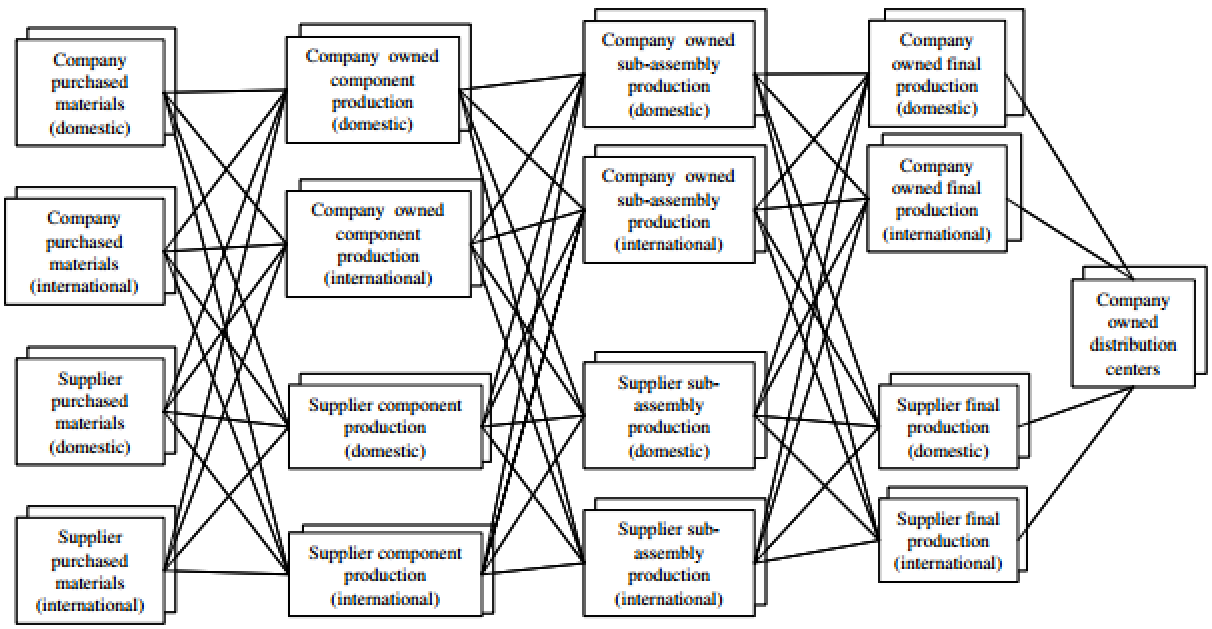

Fig. 1. Alternative production locations in a global supply chain.

A supply chain design problem comprises the decisions regarding the number and location of production facilities, the amount of capacity at each facility, the assignment of each market region to one or more locations, and supplier selection for sub-assemblies, components and materials (Chopra and Meindl, 2004). Global supply chain design extends this definition to include selection of facilities at international locations, and the special globalization factors this involves. These design decisions may be decentralized, such that a manager at each facility makes decisions, or may be centralized so that decisions across facilities are coordinated. Ideally, managers make these choices consistent with the firm's supply chain strategy.

1.1 Ongoing issues in global supply chain design

International manufacturing sources—whether company-owned or external suppliers—have in recent years been sought out by managers because of reduced cost, increased revenues, and improved reliability. Manufacturers typically set up foreign factories to benefit from tariff and trade concessions, low cost direct labor, capital subsidies, and reduced logistics costs in foreign markets (Ferdows, 1997). Likewise, benefits accrue due to access to overseas markets, organizational learning though close proximity to customers, and improved reliability because of close proximity to suppliers (MacCormack et al., 1994).

However, experts maintain that global supply chains are more difficult to manage than domestic supply chains (Dornier et al., 1998, Wood et al., 2002 and MacCarthy and Atthirawong, 2003). Substantial geographical distances in these global situations not only increase transportation costs, but complicate decisions because of inventory cost tradeoffs due to increased lead-time in the supply chain. Different local cultures, languages, and practices diminish the effectiveness of business processes such as demand forecasting and material planning. Similarly, infrastructural deficiencies in developing countries in transportation and telecommunications, as well as inadequate worker skills, supplier availability, supplier quality, equipment and technology provide challenges normally not experienced in developed countries. These difficulties inhibit the degree to which a global supply chain provides a competitive advantage.

Furthermore, global supply chains carry unique risks that influence performance, including variability and uncertainty in currency exchange rates, economic and political instability, and changes in the regulatory environment (Dornier et al., 1998). Currency exchange rates affect the price paid for goods that are purchased in the supplier's currency and so influence the timing and volume of purchases as well as the financial performance of the supply chain (Carter and Vickery, 1988 and Carter and Vickery, 1989). Accordingly, practitioners are well advised to factor these risks into their decisions when designing global supply chains.

1.2. Emerging issues in global supply chain design

To aid managers in solving these problems, the research community has developed numerous global supply chain design models. The business environment that surrounds the global supply chain problem is continually changing, however, as new issues in supply chain management and globalization surface. First, firms are increasingly outsourcing to both domestic and global locations. Second, many firms that had viewed their sourcing problems myopically as an enterprise-level concern now strive to integrate decision processes across tiers in the supply chain. A third issue is the broadened definition of supply chain performance, as mission, strategy and objectives can vary considerably based on the value of the product offered to the customer (Keeney, 1994).

Outsourcing manufacturing to offshore supplier locations is a practice that has grown in recent years such that managers find themselves increasingly designing supply chains that include not only corporate but also supplier facilities. Supplier selection decisions change the global supply chain design problem in fundamental ways, in part because they are based on more broadly defined criteria. Suppliers are typically selected based on the buyer's perception of the supplier's ability to meet quality, quantity, delivery, price and service needs of the firm (Leenders et al., 2002). In some cases, purchasing managers consider an even broader set of criteria as defined by the total cost of ownership to include the cost of carrying inventory, repair, training, disposal, etc. (Ellram, 1995, Degraeve and Roodhooft, 1999 and Burt et al., 2003). Ultimately, purchasing managers summarize these factors so that candidate suppliers may be ranked for selection.

Supplier contracts also influence the design problem structure with additional factors such as minimum order quantities, restrictions on the number of vendors, geographic preferences, and limitations on supplier capacities (Pan, 1989).

A second emerging issue—the integration of decisions across the supply chain—also influences global supply chain design. Integrating business processes is a best practice in supply chain management that involves coordinating decisions across multiple facilities and tiers. In practice, firms engaged in Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting, and Replenishment (CPFR) integrate replenishment planning between enterprises by sharing sales and promotion information (Sherman, 1998 and Lewis, 1999). Similarly, firms that implement Advanced Planning Systems (APS) may integrate production decisions across the supply chain by including supplier inventory and capacity constraints into their scheduling function, striving to avert supply problems before they occur (Rohde, 2000 and Bowersox et al., 2002). These integration practices also affect global supply chain design. Several authors (Dornier et al., 1998, Brush et al., 1999 and Trent and Monczka, 2003) discuss the value and need for integration between facilities in the global supply chain. An integrated, well-coordinated global supply chain is difficult to duplicate and so plays an important role in competitive strategy.

To date, much of the emphasis in supply chain management has been on cost reduction, but performance in real-world supply chains has multiple attributes. As defined in the Supply Chain Operations Reference (SCOR) model, performance is measured in terms of reliability, responsiveness, flexibility, cost, and assets (Supply-Chain Council, 2003).

Additionally, Handfield (1994) mentions five benefits for companies who choose to source globally—improving quality, meeting schedule requirements, reducing cost, accessing new technologies, and broadening the supply base. For example, throughout the 1990s, a number of firms adopted a quick-response strategy to improve competitiveness (Hammond, 1990 and Lowson et al., 1999). Authors such as Bozarth et al. (1998) suggest delivery performance and quality as important measures in global supply chain management. Firms that had previously looked to their international manufacturing sites as a source of low-cost advantage now rely on their global production sites for improved access to customers, suppliers and skilled employees (Ferdows, 1997). Managers who design global supply chains need to align their decisions with the mission, objectives, and strategy of their firm, which is considerably broader in scope than cost reduction.

1.3. Plan for this research

The purpose of this paper is to assess how well the existing model-based literature supports the global supply chain design problem, in light of these ongoing and emerging issues in the global environment. Our contributions are threefold: the development of a classification scheme that is focused on these practical considerations, a structured review that provides a guide to earlier research on the subject of global supply chain design models, and identification of research issues for future investigation. In the next section, we describe the methodology for the review. Section 3 summarizes the selected research, followed in Section 4 by an analysis relative to the practical issues in global supply chain design. In Section 5, we draw conclusions and suggest future research directions.

2. Review methodology

In this review, we focus on the model-based literature that addresses the global "supply chain design" problem. An alternate term in the research literature is "supply network design", used by some authors to signify that supply structures are often more complex than that suggested by a chain. We used these and related keywords, and limited our selection to articles that describe global supply chain design models that incorporate international issues, variables, parameters and constraints. Global supply chain design models are in a special class and distinct from general supply chain design models, due to the differences in cost structure and complications of international logistics.

With this scope in mind, we conducted a search using library databases covering the major journals in management science and operations management, such as *Decision Sciences*, *European Journal of Operational Research*, *Interfaces*, *International Journal of Operations and Production Management*, *International Journal of Production Economics*, *International Journal of Production Research*, *Journal of Operations Management*, *Management Science*, *Operations Research*, *Production and Operations Management*, *Transportation Research*, etc. We also searched edited books and special issues on supply chain management in *Production and Operations Management* (1997, 2002), *Decision Sciences* (1998, 2002), *Interfaces* (2000), and *Industrial Marketing Management* (2004).

From these sources, we selected articles that span a little more than two decades, from 1982 to 2005. More than 100 articles and books appeared on the subject of global supply chain management during this period, so we screened them to a list of about 80 pertinent references on global supply chain design. Of these, 25 model-based articles were selected and summarized. In most cases, a representative publication was selected from those authors who have published numerous papers and reports on the subject, narrowing the list to 18 major research articles published in 12 journals and 1 book. When clustered on a temporal basis, four of the articles were published prior to 1990, four in the 1991–1995 period, six in the 1996–2000 period, and four after year 2000.

Several earlier literature reviews have been conducted on aspects of global supply chain design. These include Verter and Dincer, 1992, Verter and Dincer, 1995, Vidal and Goetschalckx, 1997, Goetschalckx et al., 2002, Cohen and Mallik, 1997, Cohen and Huchzermeier, 1999 and Schmidt and Wilhelm, 2000. Many of these reviews seek a missing technical feature in the existing model-based literature concerning global supply chain design. Our review differs in purpose, as we seek to assess how well existing models support global supply chain design decisions in light of globalization difficulties, outsourcing, integration, and strategic alignment.

To assess this fit, we use four dimensions—decision variables, performance measurement, supply chain integration, and globalization considerations. The most common decision variables in these models are facility selection, production/shipment quantities, and supplier selection. We also identify other decision variables from the model descriptions. The performance measurement dimension identifies the nature of the objective function and other performance constructs such as constraints where they occur. For the supply chain integration dimension, we use a category for the number of supply chain levels evaluated in the model, another for whether a bill of material is specified, and a third for the type of coordination. For globalization considerations, we use the following categories: tariffs and duties, non-tariff trade barriers, currency exchange rate, corporate income tax, transportation time, inventory cost, worker skill and availability, and industry context. The currency exchange rate category reflects the use of conversion factors, as well as explicit consideration for variability or uncertainty in the exchange rate. We account for each of these dimensions as reported by the authors in the research articles.

3. Global supply chain design models

In this section, we review the selected research articles in chronological order. This ordering reflects both the issues that were important in global supply chain design at that time as well as the decision and information technologies available to solve these problems. In Table 1, Table 2, Table 3 and Table 4, we summarize the characteristics of the models along the four review dimensions.

Table 1
Decision variables

	Facility selection	Production/shipment quantities	Supplier selection	Other
Hodder and Dincer (1986)	×	×		• Financing patterns
Breitman and Lucas (1987)	×		×	• Capacity expansion • Production allocation
Cohen and Lee (1989)	×	×	×	• Interplant transhipments
Cohen et al. (1989)	×	×	×	
Haug (1992)	×			• Production shifting
Kogut and Kulatilaka (1994)	×			• Production shifting
Arntzen et al. (1995)	×	×		
Gutierrez and Kouvelis (1995)			×	
Canel and Khumawala (1996)	×	×		
Rosenfield (1996)	×	×		
Huchzermeier and Cohen (1996)	×	×		
Kouvelis and Gutierrez (1997)				• Inventory stock level
Dasu and de la Torre (1997)	×	×		• Production shifting
Munson and Rosenblatt (1997)	×	×	×	
Vidal and Goetschalckx (2001)	×	×		• Transfer price • Transportation mode • Allocation of transportation cost among subsidiaries
Hadjinicola and Kumar (2002)	×			
Lowe et al. (2002)	×	×		• Capacity
Nagurney et al. (2003)	×	×		• Equilibrium prices

"×" denotes that variable is included in the model.

Table 2
Performance measurement

	Objective and other performance constructs
Hodder and Dincer (1986)	• Maximize mean-variance of after-tax profit
Breitman and Lucas (1987)	• Varies-profit, market penetration, facility utilization, export/import levels, production, sales, costs, losses, investment-depending on business environment and assumptions
Cohen and Lee (1989)	• Maximize after-tax profit
Cohen et al. (1989)	• Maximize after-tax profit
Haug (1992)	• Minimize material/labor/transportation/utility costs • Adjusted for learning effects and discounted to present value
Kogut and Kulatilaka (1994)	• Minimize production, shutdown, and startup costs • Value of flexibility with uncertain exchange rates
Arntzen et al. (1995)	• Minimize cost and/or weighted activity time
Gutierrez and Kouvelis (1995)	• Minimize fixed and variable costs • Robustness across pre-defined scenarios
Canel and Khumawala (1996)	• Maximize after-tax profit
Rosenfield (1996)	• Minimize production and transportation costs
Huchzermeier and Cohen (1996)	• Maximize after-tax profit • Value of flexibility with uncertain exchange rates
Kouvelis and Gutierrez (1997)	• Minimize shortage/overage costs
Dasu and de la Torre (1997)	• Maximize operating profit
Munson and Rosenblatt (1997)	• Minimize sum of production and purchase cost
Vidal and Goetschalckx (2001)	• Maximize after-tax profit
Hadjinicola and Kumar (2002)	• Profit computation (descriptive model)
Lowe et al. (2002)	• Minimize production and transportation costs • Filtering process for difficult-to-quantify costs and qualitative impacts
Nagurney et al. (2003)	• Maximize utility (revenues—costs) for manufacturers and retailers

Table 3
Supply chain integration

	Supply chain levels	BOM specified?	Coordination of decisions
Hodder and Dincer (1986)	2	No	Multiple production sites for multiple markets
Breitman and Lucas (1987)	Not specified	Yes	Not specified
Cohen and Lee (1989)	4	Yes	Multiple production tiers for multiple markets
Cohen et al. (1989)	3	Yes	Multiple production tiers for multiple markets
Haug (1992)	2	No	Multiple production sites for multiple markets
Kogut and Kulatilaka (1994)	2	No	Multiple production sites for a single market
Arntzen et al. (1995)	Multiple	Yes	Multiple production/distribution tiers for multiple markets
Gutierrez and Kouvelis (1995)	2	No	Multiple supplier sites for multiple production sites
Canel and Khumawala (1996)	2	No	Multiple production sites for multiple markets
Rosenfield (1996)	2	No	Multiple production sites for multiple markets
Huchzermeier and Cohen (1996)	3	No	Multiple production tiers for multiple markets
Kouvelis and Gutierrez (1997)	2	No	Multiple production sites for multiple markets
Dasu and de la Torre (1997)	2	No	Multiple production sites for multiple markets
Munson and Rosenblatt (1997)	3	Yes	Multiple supplier and production sites for multiple markets
Vidal and Goetschalckx (2001)	4	Yes	Multiple production/distribution tiers for multiple markets
Hadjinicola and Kumar (2002)	2	No	Multiple production sites for multiple markets
Lowe et al. (2002)	2	No	Multiple production sites for multiple markets
Nagurney et al. (2003)	3	No	Single production tier and single distribution tier for multiple markets

In the models developed prior to 1990, corporate taxes, tariffs, and duties were prominent issues, and the favored technology was the production–distribution model. In the period between 1991 and 1995, variability and uncertainty in exchange rates became primary concerns, and we see that researchers developed stochastic programming and option valuation models to help address these concerns. Also during this period, researchers introduce objectives other than cost and profit—for example, activity duration is used in some cases as the performance construct. During the period from 1996 to 2000, there was continued interest in uncertainty in the parameters of the problem, as well as attention to the transfer price and supplier selection decisions. Finally, in the period after 2000, researchers again expanded technologies used to tackle these problems, developing network equilibrium models and multi-phase approaches that deploy multiple technologies.

3.1. Models developed prior to 1990

Early research on the global plant location problem appears in Hodder and Jucker, 1982,Hodder and Jucker, 1985 and Hodder and Dincer, 1986. Here, we focus on a representative publication, Hodder and Dincer (1986). In this paper, the authors studied the international plant location problem and developed a single-period model to determine the best locations, material flows and financing patterns. The model identifies the best sourcing plan given multiple possible production sites for a product to be sold in multiple markets. The authors used a function of after-tax profit as the objective, computed as the difference between net revenue, fixed cost for having a plant open, and a cost for financing that allows borrowing in multiple currencies. The cost of financing a plant is managed in the objective function as a single period outlay that represents the sum of the acquisition and interest rate costs, in the numeraire currency (i.e., of the firm's home country), adjusted using the appropriate currency exchange rate. In this way, the model includes both the costs and revenues shared across facilities, with a single time period that is sufficiently long to reflect both the decisions and their consequences on the global operation.

Hodder and Dincer (1986) also included the impact of financing arrangements, such as subsidization from local governments and reduction in corporate tax rates. The model uses a mean-variance structure in the objective function to evaluate the risk associated with uncertain price and exchange rates, allowing for correlation between price changes in global markets. The authors provided an approximation procedure that allows for solving problems that are typical of those observed in practice. The authors also allowed for several global cost factors, such as production and transportation costs, tariffs, taxes, and the appropriate exchange rate. However, the authors did not mention an industry application.

Breitman and Lucas (1987) described the PLANETS model, developed at General Motors to assist in making decisions concerning facility location, capacity planning, material sourcing, product allocation, and new product introduction. PLANETS is a tool for building mixed integer programming models that are reportedly capable of providing optimal solutions to difficult global sourcing problems. The model maximizes any of a variety of objectives, depending on the particular assumptions and business environment, including profit, market penetration, facility utilization, exports, production, sales, costs, losses, investment, and imports. The authors use a bill of material constraint in the model to allow for complex product structures that explicitly link the quantity relationships between the facilities over multiple tiers in the global supply chain.

Breitman and Lucas (1987) modeled a number of features relating to global supply chains, including tariffs, local content, balance of trade, and trade complementation. Global parameters in the model include currency exchange rates and transportation costs. The authors did not provide the model formulation in the paper, and the level of integration in the supply chain was not specified. The authors state that the model has been applied to numerous studies in the automotive industry.

Cohen and Lee (1989) developed a global supply chain model and then evaluated a series of policy options that a firm might use to establish a global manufacturing strategy. This production–distribution model consists of four tiers—component suppliers, final assembly plants, distribution centers, and market locations. The model's time horizon is such that the decisions and associated costs occur in a single yet sufficiently long time period. The objective maximizes total global after-tax profits, including taxes, tariffs and transfer prices, all adjusted for varying but known exchange rates. Because of the implications of corporate taxes on the revenue function, the model is non-linear with both integer and linear variables.

In Cohen and Lee (1989), the supplier and assembly plant tiers are linked using a bill of material specified as a usage rate in the constraint set. The model selects vendors based on both fixed and variable costs, and bounds the flows from the supplier plants for minimum and maximum supply capacities. The authors stated that a realistic problem could likely not be solved in its entirety, and proposed a hierarchical procedure that relaxes the integer constraints. The paper describes a case study application from the personal computer manufacturing industry.

Cohen et al. (1989) developed a global supply chain model to address the manufacturing decisions faced by companies that produce and source globally. The model is a multi-period, production–distribution model with time-varying parameters that solves for both location and material shipment quantities over time. The decision variables are supplier choice, the production quantity at each plant, and the amount of product supplied to each market. The objective maximizes after-tax profits subject to material flow constraints, plant capacity, market penetration strategies and local content rules.

Cohen et al. (1989) included a fixed-cost structure that allows for economies of scale in the production–distribution network. Other factors included tariffs, currency exchange rates, and corporate tax rates. The model calculates after-tax profit based on transfer prices, but the prices are an input and not a decision variable in the model. The model specifies vendor contract alternatives for cost, duration and volume limits, providing supplier selection capabilities that are uncommon but generally beneficial in supply chain design models. The model allows for three supply chain tiers and provides for specification of a bill of material in its constraint set. The authors did not mention an industry application in this paper.

3.2. Models developed in the 1990–1995 period

Haug (1992) developed an international location model to study the global sourcing problem in high technology firms. The model identifies the best sourcing plan given a set of possible production sites for a product to be sold in multiple markets. The model is distinct in that it explicitly recognizes learning-curve effects on both material and labor costs, and allows for production to be transferred from site to site in response to improved input costs or exchange rates. Because of learning curve effects, a penalty would be incurred at a new site until it becomes as efficient as a former site. The model excludes fixed relocation costs because the supplier firms, joint ventures, and internal facilities are previously established. Therefore, these charges are not incurred if and when production is transferred.

The model described in Haug (1992) includes variable costs that are typically considered in location models, such as material, labor, transportation, and utilities. The output of the model is a location sequence. In other words, the model identifies the best location for production, allowing production to be transferred from one site to another site at the beginning of each year. Three types of globalization considerations are explicitly considered in the model—exchange rate variability, inflation variability, and changes in worker skill over time. However, the authors did not mention an industry application.

Kogut and Kulatilaka (1994) developed a stochastic, dynamic programming model to study the value of production switching in conditions where currency exchange rates are uncertain. In this way, the authors investigated the flexibility of a manufacturing system that allows production to be transferred as currency exchange rates fluctuate. The decision to stay to a production facility with unfavorable exchange rates versus shifting production to a facility with more favorable rates is complicated by switching costs—shutdown and startup costs, labor related costs, and managerial time commitments.

Kogut and Kulatilaka (1994) assumed that demand is independent of price and structured the model to minimize a vector of factor costs, which includes transportation cost from the production facility to the market. The model allocates production for a single product in a single market location to a set of possible production locations. The authors provided a numerical example without identifying a specific industry application.

Arntzen et al. (1995) developed a mixed integer program to solve the global supply chain design problem at an electronics manufacturer, Digital Equipment Corporation, now part of the Compaq Corporation. The decision variables in the model are location selection and production, inventory and shipping quantities. The model minimizes fixed and variable production costs, inventory costs, and distribution expenses, including transportation, taxes, and duties with consideration for local content, offset trade, and duty drawback. The model solves supply chain problems that involve multiple products, production stages, time periods, and transportation modes. The model is highly integrative, since it links multiple supply tiers by the bill of material, and solves for the optimal solution over both production and distribution segments of the supply chain.

A distinguishing feature of the model by Arntzen et al. (1995) is its ability to reflect both cost and time in the objective function. Time is measured as the number of days needed for production and for transit on each link in the supply chain, weighted by the number of units processed or shipped on the link. Thus the overall response time of the supply chain can be minimized as an alternative objective. In fact, the objective function may be a weighted combination of cost and time so that either measure or both can be used to derive recommendations.

Gutierrez and Kouvelis (1995) developed a model and an algorithm for international sourcing with uncertain currency exchange rates and investigated the utility of operational flexibility to hedge against losses in this environment. The model minimizes the sum of fixed and variable costs and selects suppliers for a global network that allows for production switching when exchange rates fluctuate. The fixed costs represent the costs of developing a particular supplier location, such as joint engineering, transfer of technology, and quality improvement programs. The variable cost is the purchase price, which includes transportation cost and import/export taxes. The authors allowed for minimum purchase quantities in the model by breaking the variable costs into two parts—costs associated with the minimum purchase quantity, and costs for production in excess of the minimum.

Gutierrez and Kouvelis (1995) structured this international sourcing model using a min-max formulation so as to identify a supply network that is robust to changes in exchange rates. Specifically, the company entities included in the supply network are selected to minimize the performance range under all exchange rate scenarios and so provides a robust solution. This research was extended in Kouvelis et al. (2001) to investigate ownership structure and the exchange rate conditions under which exporting, joint ventures, or wholly owned production facilities are appropriate.

3.3. Models developed in the 1996–2000 period

Canel and Khumawala (1996) developed un-capacitated and capacitated versions of a mixed integer programming model to solve an international facility location problem (IFLP). The objective maximizes after-tax profits, including costs for investment, fixed, transportation, shortage, and inventory holding. The model selects multiple production sources for end-product manufacturing but not the supply segments. Prices are a parameter of the model and vary by selling country, so when production is limited the model chooses the best customer locations for each facility. The model includes a number of features relating to global supply chains, including exchange rates, corporate tax rates, tariffs, and direct export incentives. The authors illustrated the model using a case study from the chemical industry.

Canel and Khumawala (1997) extended the IFLP model by including multiple periods so that timing of location changes can be more carefully evaluated. Later, Canel and Khumawala (2001) focused on heuristic procedures to solve the IFLP problem. Canel and Das (2002) extend this research line with a model that integrates manufacturing and marketing decisions in a global context.

In Rosenfield (1996), the author developed a model to describe production and distribution costs for an international location problem and then explored its structural properties to draw insights on location and capacity strategies when exchange rates are uncertain. The model assumes that production may be switched between locations without cost and without time lags. The author evaluated policies relating to the use of excess capacity in the supply chain to support flexibility in sourcing—i.e., the practice of installing excess capacity across diverse international locations to provide opportunity for production switching in reaction to market changes. The model is limited in that it does not consider quotas, tariffs, duties, and corporate tax rate differentials. The ideas proposed in the paper had been tested with Polaroid's camera and film businesses and with Motorola's cellular phone business.

Huchzermeier and Cohen (1996) developed a stochastic dynamic programming model to investigate the value of operational flexibility where currency exchange rates are uncertain and switching costs are incurred. This work is similar to earlier papers in that the value of production flexibility is investigated, but Huchzermeier and Cohen developed a modeling framework that integrates a production–distribution network flow model with an option valuation model that establishes the option value of operational flexibility for production location changes as exchange rates fluctuate. The model selects suppliers, final production locations, and market regions and solves for shipment quantities on all linkages of the three-tier supply chain. The objective maximizes after-tax profit over a multi-year planning horizon. The paper provided a solution algorithm and addressed implementation issues, but didn't identify an industry application.

In Kouvelis and Gutierrez (1997), the authors formulated and solved a global newsvendor model for style goods in the apparel industry. The model solves for production quantities of each item by minimizing the sum of the shortage and overage costs for multiple production sites and multiple markets. The shortage cost represents the opportunity cost of lost sales, and the overage cost is the loss due to selling the item at salvage value at the end of the selling season. The model includes the effects of transfer prices and the uncertainty in exchange rates, but excludes other global costs such as taxes and tariffs.

Note that since the model in Kouvelis and Gutierrez (1997) solves for production quantities only, it is not a design model per se, but it may be used to evaluate alternative supply chain design schemes. The authors investigated both centralized and decentralized decision-making structures for the problem, and found that centrally coordinated production decisions are most advantageous for the firm as expected. There are, however, implementation difficulties and control problems associated with central coordination. The authors tested alternative transfer pricing strategies and found that penalties for decentralization can be virtually eliminated by careful selection of a transfer pricing scheme.

Dasu and de la Torre (1997) developed a model that describes the price-setting and production allocation processes for multinational corporations supported by a network of partially owned subsidiaries. The authors used a game theoretic framework for their model, as opposed to a production–distribution network model, and analyzed two decision-making structures for the supply chain for a textile fiber manufacturer. By developing both decentralized and centralized models, the authors were able to assess the advantage of coordinating prices among the subsidiaries. The model includes tariffs, currency exchange rates, and transportation costs, but not supplier tiers or a bill of material. The authors used these models to study a textile fiber company with partially owned Latin American subsidiaries.

Munson and Rosenblatt (1997) investigated a global supply chain problem that emphasizes supplier sourcing with local content rules. These rules require that a firm purchase a specified quantity of components from suppliers within the country where it opens a manufacturing plant. The authors stressed the growing importance of local content restrictions in global sourcing by noting that treaties such as NAFTA favor the use of suppliers within the trading block. The mixed integer program selects suppliers and final production sites, and allocates purchase quantities for a particular market to minimize the sum of purchasing, production, transportation, and fixed costs. The fixed costs in this model result from opening and operating a plant in a specific country.

Munson and Rosenblatt (1997) included provisions in the model for a bill of material, local content, and supplier capacity constraints. This paper was primarily methodological, but also discussed the implications of regulatory policy on industry. Although the authors mentioned industries that experience this type of global sourcing, they do not develop an application in this paper.

3.4. Models developed since 2000

Vidal and Goetschalckx (2001) developed a global supply chain model to address design problems relating to a multinational corporation that outsources some but not all of its production to supplier facilities. This model simultaneously selects facility locations, computes flows between facilities, sets transfer prices, and allocates transportation costs to either the shipper or the receiver to maximize after-tax profits across multiple tiers in the supply chain. Supplier selection is outside of the scope of the authors’ design problem, however, so the location decisions are not integrated across the production and supplier tiers.

In the Vidal and Goetschalckx (2001) model, the component costs are transfer prices when supplied by internal production locations, and market prices for external suppliers. The model evaluates global supply chain costs, which include tariffs and corporate income taxes. The authors specified a bill of material constraint to allow for complex product structures over multiple tiers that explicitly link the quantity relationships between the facilities in the global supply chain. The mode choice decision in the model considers the trade-off between transportation and pipeline inventory costs, so that a high inventory value of product in-transit may offset the high cost of air transport.

The Vidal and Goetschalckx (2001) model is a non-convex optimization model with a linear objective function and both linear and bilinear constraints to represent this problem. The solution methodology is a heuristic algorithm that decomposes the model into a set of Linear Programming sub-problems, and then iterates until an optimal or a satisfactory solution is found. The authors evaluated the heuristic with test problems, but no particular industry was identified as a basis in the creation of the computational examples.

Hadjinicola and Kumar (2002) took a broader approach by combining manufacturing and marketing functions into a global supply chain model that they then used to assess eight manufacturing-marketing strategies. Specifically, the authors developed a model of market share as a function of product attributes and then incorporated production and inventory costs for the specific locations as inputs to the revenue and profit models. The model is descriptive, so there is no decision variable per se. However, the authors identified and evaluated strategic alternatives using the cost and revenue functions described in the paper. As location is a primary factor in the production and inventory cost functions, the methodology serves as a useful approach for evaluating alternative supply chain structures.

Hadjinicola and Kumar (2002) assumed that production costs vary linearly with product attributes and allowed for exchange rates, inventory costs and transportation costs in their analysis. However, the model does not include the supply segments of the supply chain—it considers only the end-product manufacturing location for a set of markets. The authors did not mention an industry application in this paper.

Lowe et al. (2002) developed a two-phase multi-screening approach for incorporating uncertainty about exchange rates and exchange rate risk in an international production and sourcing model. The decision variables in this model are the location of production facilities and how much capacity to place at each of these plants. The premise is that it will be beneficial to the manufacturer to plan for some additional capacity to allow for production shifting as exchange rates fluctuate. The authors used scenarios to represent possible realizations of real exchange rates, incorporating uncertainty for both nominal currency exchange rates and inflation.
The cost structure in Lowe et al. (2002) is generic in that it comprises fixed and variable costs for each candidate location in the problem, including but not limited to transportation and duties. The method also allows for qualitative factors such as worker availability. The supply chain in the model allows for multiple locations at one production and one market tier. The authors provided an example based on the Applichem case study (Flaherty, 1985) to illustrate their approach for evaluating these strategies.

Nagurney et al. (2003) developed a network equilibrium model for a global supply chain comprised of three tiers—manufacturer, retailer, and consumer. The model uses a variational inequality formulation to derive product shipments and price patterns in the network, assuming cooperation between tiers but competition within tiers. The equilibrium model maximizes profit at each tier in the supply chain subject to the customer's willingness to pay, considering production costs for the manufacturer, transaction costs associated with obtaining the product, and exchange rate appreciation over time. The cost functions are all assumed to be convex and continuously differentiable. Inventory costs may be included as part of the transaction cost function at any and all tiers.

In Nagurney et al. (2003), the model considers fluctuation in currency exchange rates. Since the model describes the distribution segments of the supply chain only where the product is the same from the manufacturer to the retailer to the consumer, a bill of material structure is not required. The paper did not identify an industry application.

4. Discussion

In Table 1, we list the decision variables in each supply chain model. Most of the models (16 out of 18) select locations for production and/or distribution facilities in global supply chains, although each model has limitations. Twelve of the models solve for material flows in the form of production/shipment quantities between production, distribution and market locations. Note from Table 1 that only five of the models—Breitman and Lucas, 1987, Cohen et al., 1989, Cohen and Lee, 1989, Gutierrez and Kouvelis, 1995 and Munson and Rosenblatt, 1997—solve the supplier selection problem, a shortcoming considering the extent of outsourcing in practice today. Two of the models also address how much capacity should be made available and when—Breitman and Lucas, 1987 and Lowe et al., 2002. We also see financing arrangements (Hodder and Dincer, 1986), product allocation (Breitman and Lucas, 1987), production shifting (Haug, 1992 and Kogut and Kulatilaka, 1994), and transportation mode selection (Vidal and Goetschalckx, 2001) listed as decision variables in these models.

Table 2 is a summary of the performance measures addressed in the selected global supply chain design models. The table shows that half of the models (9 of the 18) address profit, operating profits or after-tax profit. For most of these models, the focus is selecting production locations in a multinational corporation, and so corporate taxes and transfer prices are important factors. At the same time, these elements cause non-linearity in the objective function and so the problem is more difficult to solve. Eight of the remaining models minimize cost, and one—Arntzen et al. (1995)—may be used to explicitly minimize time instead of cost or profit.

These authors also address a few other important performance measures. Two of the articles—Kogut and Kulatilaka, 1994 and Huchzermeier and Cohen, 1996—consider flexibility in global supply chains by proposing a cost-based model and then investigating the value of having options to assign production to facilities after observing actual currency exchange rates. One author—Gutierrez and Kouvelis (1995)—develops a model that maximizes robustness of the cost-based solution, also under conditions of uncertain currency exchange rates. Note however that these implementations have a cost focus. Even though supply chain performance has broadened in scope, the research community in global supply chain modeling has not yet given due attention to alternative objectives.

Table 3 illustrates that existing models allow for minimal integration in the global supply chain. Specifically, we see that ten of the models consider sourcing decisions between just two of the tiers. Modeling the bill of material is important for analyzing the coordination of decisions when supplier structures are considered, yet only six of the models—Breitman and Lucas, 1987, Cohen et al., 1989, Cohen and Lee, 1989, Arntzen et al., 1995, Munson and Rosenblatt, 1997 and Vidal and Goetschalckx, 2001—provide a bill of material constraint to allow for complex product structures over multiple tiers in the global supply chain.

The third dimension in Table 3—coordination of decisions—also shows limited opportunity for improving global supply chain performance with this set of models. Supply chain coordination is most constrained when the decision is to select production sites for a single product in a single market location, as is the case in one of the models—Kogut and Kulatilaka (1994). Seven of the models coordinate decisions for multiple production sites for multiple markets. Two models consider multiple supplier sites for multiple production sites—Gutierrez and Kouvelis, 1995 and Kouvelis and Gutierrez, 1997. The greatest degree of coordination is across multiple production–distribution tiers for multiple markets. There are six cases of this type—Cohen et al., 1989, Cohen and Lee, 1989, Arntzen et al., 1995, Munson and Rosenblatt, 1997, Vidal and Goetschalckx, 2001 and Nagurney et al., 2003.

Table 4 summarizes the findings concerning globalization considerations in the selected models. Note that all models provide an exchange rate parameter to convert local currencies to a common currency. Six of these provide for variability in the exchange rate using a time index, and seven use a random variable to provide for analysis of the effects of uncertainty on the global supply chain design problem. Eleven of the models incorporate tariffs or duties, and eight consider non-tariff barriers—but there are fewer examples of these in later years than in early years. Corporate income taxes are considered in eight of the models, important in multinational corporation supply chains. Most of the models provide the structure to explicitly evaluate the impact of extraordinary transportation costs in global supply chains, but only two—Arntzen et al., 1995 and Vidal and Goetschalckx, 2001—incorporate the impact of long transit times in cost terms.

Note also from Table 4 that inventory cost appears in just five of the models—Arntzen et al., 1995, Canel and Khumawala, 1996, Vidal and Goetschalckx, 2001, Hadjinicola and Kumar, 2002 and Nagurney et al., 2003. This lack of attention is likely due to the research community's practice of decomposing a difficult problem into smaller, manageable components. Although there are exceptions beyond the global supply chain literature (e.g., Shen et al., 2003), the research community has typically viewed inventory as a tactical decision and managed the problem independently by identifying policies to minimize inventory cost only after the design decision is made.

Finally, we see that half of the models (9 out of 18) were developed in the context of a specific industry application. Certainly industry-based and general models each have their merits. Industry-based models bring new empirically motivated research issues to light, while general models allow researchers to focus on difficult aspects of the problem and find new methods for solving them. Yet the range and coverage of industries explored in the context of global supply chain modeling appears to be limited, suggesting a need for further research in these areas.

5. Conclusions

In this paper, we review the model-based literature for the global supply chain design problem, and examine it using dimensions related to ongoing and emerging issues in supply chain globalization. Overall, we find that although the research community has tackled some of the most difficult global supply chain issues, few models comprehensively address outsourcing, integration, and strategic alignment in global supply chain design.

First, we conclude that *global supply chain models need to address the composite supply chain design problem by extending models to include both internal manufacturing and external supplier locations*. Manufacturers rarely own the facilities in their supply chains, yet managers aim to achieve a well-designed supply chain. Supply chains typically comprise both internal and external facilities, and this reality needs to be taken into account in global supply chain design models. Pan, 1989 and Munson and Rosenblatt, 1997 identify important selection criteria for designing these composite global supply chains. These criteria include minimum vendor order quantities, budget constraints, number of vendors, geographic preferences, and capacities. In addition, these models should have objectives or constraints to evaluate the impact quality, lead-time and service level in the global supply chain design problem. In the model set we evaluated, few authors considered these factors.

We also conclude that *global supply chain models need broader emphasis on multiple production and distribution tiers in the supply chain*. Many of the models reviewed here address only the first tier of manufacturing, neglecting the performance implications of the suppliers of goods and services. As illustrated in Lee, 2000, Rohde, 2000 and Krajewski and Wei, 2001, there are opportunities for integrating decisions across tiers as well. The supply chain model should include enough supplier tiers to allow investigation of the interactions in the sourcing of major components and material. Without multiple tiers in the global supply chain design model, the ability of supply chain managers to integrate decisions is limited to coordination within the tier. A third conclusion we draw is that *the performance measures used in global supply chain models need to be broadened in definition to address alternative objectives.* The Supply-Chain Council (2003) identifies five performance metrics for supply chains—reliability, responsiveness, flexibility, cost, and assets. For global supply chains, Handfield (1994)also identifies access to new technologies and broadened supply base as benefits. Although real-world supply chains emphasize a variety of performance measures in practice—very few global supply chain design models allow for this variety.

Finally, we find that *more industry settings need to be investigated in the context of global supply design*. A number of industries have been explored in the model-based literature, including electronics manufacturing, apparel, fiber and textile, and automotive. Other industries have not been investigated, such as aircraft, heavy machinery, and services. The challenge for any particular industry is to strategically decide on those features that will be modeled, to keep the problem tractable, and thereby focus on the special structure of the practical setting. Without a focus, the amount of data required are unnecessarily numerous and may be prohibitively time consuming. This shortcoming represents an important gap between model development and implementation in practice.

Future research should focus on multi-tier supply chains with both internal production sites and external suppliers, and encompass more performance criteria and a wider variety of industries. The insights identified in this paper will help channel research efforts along these lines to be both forward-looking and practical. In closing, we see continuing opportunity for the development of global supply chain design models in future research.

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