Logistics and Transportation in Global Supply Chains: Review, Critique, and Prospects

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Abstract  A supply chain denotes the series of operations by which raw materials are transformed into components, subassemblies, and finished goods, and then moved through a distribution system to the ultimate user or consumer of the item produced. Product transformation and storage occur at nodes of the network. When those are in different countries or areas of the world, logistics and transportation (between nodes) become even more important.

In this tutorial, we review and compare a number of research papers. All are international in scope. Each article emphasizes one or more decisions or activities that distinguish a global supply chain. Some, such as location decisions and supplier selection, are important for domestic supply chains but are more complicated in the international arena. Major differences include border crossings and exchange rates. Other decisions, such as switching production from one country to another, are uniquely global and may depend upon tariffs, quotas, and local content restrictions.

Following our rationale for the subset of literature that we chose, those articles are discussed, categorized, and compared in several complementary ways. An assessment is offered of the research conducted to date. Further studies that may be usefully undertaken are suggested.

Keywords  international; operations management; intermodal; distribution; manufacturing; location; trade; NAFTA; EU; supplier selection; transfer pricing; literature review

1. Introduction

Globalization has become both a buzzword and a truism. Demand for products and services originating from across the world have made it necessary for companies to reexamine their supply chain processes to maintain competitiveness in the international arena. Competition can be in the form of new and innovative technology, but perhaps the most easily measured forms of competition are profits and costs.

Supply chain models attempt to develop optimal facility, supplier, and/or transportation networks that are the most profitable (or least costly). Expanding these models to include international locations and suppliers creates additional challenges, because exchange rate fluctuations and transfer prices may affect product costing, and transportation linkages may become more complex and expensive. However, labor costs in certain regions of the world are often so low that they can overcome the large transportation costs from there to markets, or to another location where the more technologically oriented processes will take place to complete the production of the end item.

This is the “truism” portion, that the optimal supply chain for such products may procure raw materials on one continent, and complete the manufacturing on another continent, for sale in a third. While “buzzwords” may come and go, globalization is not going anywhere anytime soon. Regional trading blocs exist in North America (North American Free Trade Agreement (NAFTA)), Europe (European Union (EU)), and Asia (Association of Southeast
Asian Nations). Firms from one region may outsource some production to a firm in another region, or they may purchase components from another region for assembly in their own.

The preceding suggests why we chose “Global Supply Chains” as part of our title. Naturally, the international movements of raw materials, components, and finished goods require excellent logistics practices. Most authors would include transportation as one of the functional areas of logistics, and so do we. But we feel that separate mention of each makes more obvious the trade-offs of transportation within decisions on inventory or location or manufacturing. These trade-offs are fundamental in logistics management. It is for this reason that the logistical activities that we discuss in this tutorial will emphasize transportation, or at least place it on a par with the other functions.

In this tutorial, we are not exhibiting a new problem formulation nor teaching a modeling technique. Rather, in light of the significance of globalization in the popular press, and of course its actual importance, we intend to put into context the vast number of references on global supply chains. We wish to offer guidance to practitioners in companies whose supply chains have become more international in scope, and to academics, we will suggest research opportunities by classifying and critiquing the available models in various ways that reinforce each other.

Naturally, a model that attempts to cover “everything” must neglect some details. A number of authors have made different choices, even in similar-sounding cases, about which factors are important. The reasons for those choices, and specific findings in the given situations, can guide future research and practice. We will show that particular applications have so far been little studied or not studied at all. We will offer suggestions for additional research and the underlying rationale.

1.1. Research Approach

Our survey is limited to journal articles pertaining to aspects of global or regional logistics published during the past 15 years. To search for articles, certain key terms and variations of them were used, such as “global logistics,” “global production distribution,” “international supply chain,” and “international transportation.” The papers were broadly (and subjectively) categorized by the following primary topics: previous review papers; facility location; procurement; transportation; production switching, transfer pricing policies, and postponement; overall networks; and other papers. (An additional search for articles was performed using the references from previous review papers if they did not appear in the initial search.) Because of the nature of some topics, papers may address multiple themes but will be discussed by the main issue or problem that they study. Also, although some articles do not discuss logistics on a global scale per se, their subjects and solution methodologies may be easily transferred to an international supply chain network.

Table 1 summarizes, by primary topic and region of focus, the references that address international logistics. The majority of papers treat global supply chains on a worldwide basis, whereas the remaining papers are fairly evenly distributed across the continents. The following five articles are not specifically global in nature but discuss topics that are applicable to international logistics. The models developed by Eskigun et al. [24] (2005) and Grasman [28] (2006) relate to multimodal routing, an aspect that is common to global transportation models. Bilgen and Ozkarahan [7] (2004), Gunasekaran and Kobu [30] (2007), and Melo et al. [51] (2009) survey topics in logistics and describe certain features that may be applicable to an international supply chain.

In the next sections, we will discuss the trends in research appearing in the reviewed literature, providing the reader with a breakdown of papers by category, global region addressed in the research, model objective, and distinguishing features. Publications will be discussed in chronological order.
Table 1. Selected papers by primary topic and region of focus.

<table>
<thead>
<tr>
<th>Primary Topic Region</th>
<th>Previous reviews</th>
<th>Facility location</th>
<th>Procurement</th>
<th>Transportation</th>
<th>Production switching, transfer pricing policies, and postponement</th>
<th>Overall network design</th>
<th>Other papers</th>
<th>Regional total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worldwide</td>
<td>8</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>14</td>
<td>4</td>
<td>6</td>
<td>44</td>
</tr>
<tr>
<td>N. America</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>S. America</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Asia/Oceania</td>
<td>2</td>
<td>1</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Topic total</td>
<td>8</td>
<td>9</td>
<td>4</td>
<td>12</td>
<td>16</td>
<td>10</td>
<td>14</td>
<td>73</td>
</tr>
</tbody>
</table>

2. Previous Review Papers

A number of review articles are concerned with the effect of globalization on supply chains (see Table 2). Bhatnagar et al. [5] (1993) research the importance of multiplant coordination in making optimal production planning decisions for an entire firm. Two variations of coordination are examined: (1) general coordination, referring to the integration of different functions such as facility location, production, distribution, and marketing; and (2) multiplant coordination, which deals with linking decisions within the same functional department across different stages of the supply chain. The authors go on to describe how multiplant coordination is affected by differences in lotsizing at various facilities, nervousness in demand, and levels of safety stock. Pontrandolfo and Okogbaa [59] (1999) also review literature pertaining to the configuration and coordination of multinational corporations (MNCs). From their research, the authors develop a framework to evaluate the current degree of coordination of a firm and to provide recommendations for improvement.

Boone et al. [10] (1996) explore relevant literature to determine if any regional differences exist in the approach to international logistics problems. As well, the authors evaluate three previously established frameworks for classification of this research. Boone et al. [10] find that no statistically significant regional differences exist in the chosen topics nor in the solution methodologies used; however, when a particular framework that is geared toward strategic classification is applied, regional trends become more apparent.

Vidal and Goetschalckx [73] (1997) conduct a review of strategic production–distribution models in global supply chains, focusing particularly on the use of mixed integer programming (MIP) as a solution approach. They tabulate the model characteristics of eight selected MIP papers, as well as international issues present in six selected global supply chain models. Vidal and Goetschalckx [73] (1997) find that most models do not take into account the volatility of global supply chains, nor do they consider bill of materials (BOM) constraints.

Table 2. Previous review papers.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhatnagar et al. [5]</td>
<td>1993</td>
<td>Multiplant coordination should address nervousness, lot sizing, and safety stock</td>
</tr>
<tr>
<td>Boone et al. [10]</td>
<td>1996</td>
<td>Determines whether a significant difference exists between regions in terms of research; classifies papers based on 3 established frameworks</td>
</tr>
<tr>
<td>Cohen and Mallik [18]</td>
<td>1997</td>
<td>Reviews the use of analytical models in global supply chain management literature</td>
</tr>
<tr>
<td>Vidal and Goetschalckx [73]</td>
<td>1997</td>
<td>Reviews production–distribution models with an emphasis on MIP</td>
</tr>
<tr>
<td>Pontrandolfo and Okogbaa [59]</td>
<td>1999</td>
<td>Develops framework for global manufacturing planning and uses to analyze an MNC’s current coordination mode</td>
</tr>
<tr>
<td>Schmidt and Wilhelm [66]</td>
<td>2000</td>
<td>Reviews papers and modeling issues addressing strategic, tactical, and operational levels</td>
</tr>
<tr>
<td>Prasad et al. [60]</td>
<td>2001</td>
<td>Detailed classification of research papers</td>
</tr>
<tr>
<td>Meixell and Gargeya [50]</td>
<td>2005</td>
<td>Assesses how well research papers address global logistics decisions</td>
</tr>
</tbody>
</table>
Some of their suggestions for future research include the consideration of more stochastic features such as customer service levels and lead times, improved modeling of BOM constraints, simulation of qualitative factors, and the inclusion of vendor and transportation channel reliability. Similarly, the review by Cohen and Mallik [18] (1997) proposes that additional focus should be placed on risk management, the benefits of economies of scale versus operational flexibility, managing the complexity arising from increased product variety, and the design of incentive systems to facilitate production switching. Certain of these features have now appeared in more recent papers.

Schmidt and Wilhelm [66] (2000) examine the strategic, tactical, and operational issues in supply chain models. For each level of decision making, the authors provide a literature review as well as typical solution methodologies employed. The authors find that (1) strategic models are normally concerned with facility location, capacity, and production technologies; (2) tactical models seek to develop appropriate material flow management policies; and (3) operational models deal with coordination of activities to meet customer service requirements.

Prasad et al. [60] (2001) provide a breakdown of literature on international operations strategies from 1986 to 1997, classifying papers by region, solution methodology, authorship, and cross-country affiliation, to name a few. They recommend that future research should focus on how internal changes such as turnover in senior management affect the implementation of strategic operations, as well as how these firms cope when falling short of performance targets.

Meixell and Gargeya [50] (2005) classify a collection of global supply chain design papers based on four dimensions: decision variables (e.g., for facility and/or supply selection), performance measurement (nature of the objective function and constraints), supply chain integration (e.g., number of supply chain tiers, type of coordination, and BOM specifications), and global considerations (such as exchange rates, tariffs, duties, trade barriers, etc.). From their research, the authors recommend that future global supply chain design models should include both the external and internal supplier locations, that more than one tier of the supply chain should be considered, a broadened definition of performance metrics should be applied, and that case studies should explore different industry settings rather than exhausting the automotive, textile, or electrical manufacturing industries.

Each of these previous reviews stresses similar areas for future research, namely, improving internal coordination, expanding the unit of analysis to include external players, and establishing appropriate targets with measurable progress. The firm’s goals need not be based solely on profit maximization or cost minimization, but rather, firms should consider other factors as Vidal and Goetschalckx [73] (1997) and Meixell and Gargeya [50] (2005) suggest. We will see in the following section how qualitative aspects are accounted for in some facility location models.

3. Facility location

Facility location models pertain to the optimal location of a variety of facilities, including distribution centers (DCs), manufacturing plants, and finishing plants. A general facility location model addresses open–close decisions for plants or DCs, how to allocate customer demand to these plants, and the quantity of product to ship to each customer market (Gourdin [27] 2006). A global facility location model is extended by including factors such as exchange rates, duties, tariffs, and local content rules. Each of these will affect how a company positions itself internationally to better take advantage of tax incentives, lower wage costs, and proximity to customers. Table 3 provides a summary of the selected facility location papers. Note that although all papers have been classified according to several criteria, only the relevant columns for each topic are shown.

In Badri [3] (1999), the author combines his previous multicriteria integer goal programming model (Badri [2] 1996) with the analytic hierarchy process (AHP). Decision makers
<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Region</th>
<th>Objective</th>
<th>Time period</th>
<th>Number of products</th>
<th>Transfer prices</th>
<th>Exchange Rates</th>
<th>Duties and tariffs</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badri [2]</td>
<td>1996</td>
<td>Asia/Oceania</td>
<td>Min cost</td>
<td>S</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td>Uses qualitative factors to aid in decision making</td>
</tr>
<tr>
<td>Canel and Khumawala [14]</td>
<td>1996</td>
<td>Asia/Oceania</td>
<td>Max profit</td>
<td>M</td>
<td>S</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>Develops a 0-1 MIP for a capacitated and uncapacitated international facilities location problem</td>
</tr>
<tr>
<td>Badri [3]</td>
<td>1999</td>
<td>Asia/Oceania</td>
<td>Min cost</td>
<td>S</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td>Extends the Badri [2] model to include the AHP and form a more systematic decision-making process</td>
</tr>
<tr>
<td>Canel and Das [13]</td>
<td>2002</td>
<td>Asia/Oceania</td>
<td>Max profit</td>
<td>M</td>
<td>S</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>Integrates manufacturing and marketing decision in a global context</td>
</tr>
<tr>
<td>Bhutta et al. [6]</td>
<td>2003</td>
<td>Asia/Oceania</td>
<td>Max profit</td>
<td>M</td>
<td>M</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>MIP model; includes decisions on production, distribution, and investments</td>
</tr>
<tr>
<td>Kouvelis et al. [41]</td>
<td>2004</td>
<td>Asia/Oceania</td>
<td>Max NPV</td>
<td>M</td>
<td>M</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Incorporates government subsidies and other incentives</td>
</tr>
<tr>
<td>Robinson and Bookbinder [63]</td>
<td>2007</td>
<td>NAFTA</td>
<td>Min cost</td>
<td>M</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td>MIP for NAFTA supply chain; includes modal decisions</td>
</tr>
<tr>
<td>Hamad and Gualda [33]</td>
<td>2008</td>
<td>S. America</td>
<td>Min cost</td>
<td>S</td>
<td>M</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Attention to value-added taxes in Brazil; inclusion of take-or-pay costs</td>
</tr>
</tbody>
</table>

**Notes.** All models in this subset assume deterministic conditions. S, single; M, multi.

*Paper has been applied to industry/used industry data.*

*NPV, net present value.*
assign weightings to qualitative global factors, such as political situations, global competition and survival, economic-related factors, and government regulations, ranking what they deem most important when considering which facilities to open or close. Badri [3] (1999) finds that this method provides consistency and a systematic methodology to solving the location-allocation problem.

Canel and Khumawala [14] (1996) present a thorough description of international factors and costs to consider for both uncapacitated and capacitated international facility location problems. The authors apply their 0-1 MIP to an actual case involving a U.S.-based multinational chemical company serving markets in North America, Europe, and the Far East. In Canel and Khumawala [15] (2001), a heuristic procedure is used to simplify this multiperiod MIP while treating qualitative international factors. By incorporating multiple periods, the model is able to take into account price, cost, and demand variations while maximizing profit.

Bhutta et al. [6] (2003) develop a mixed integer linear program to maximize profit and determine optimal capacities, investments, and production allocation for MNCs. They consider three scenarios, with varying numbers of facilities and countries, to examine the effects of exchange rates and tariff rates on locating facilities and quantities to produce at each plant. Bhutta et al. [6] show that tariff and distribution costs will offset production set up costs, and that it is advantageous for the MNC to assign some initial capacities and inventory to each plant to help decrease overall costs. Canel and Das [13] (2002) also consider exchange rates and tariffs in their profit maximization model, while realizing the interdependency that exists between marketing and manufacturing decisions.

Kouvelis et al. [41] (2004) present a comprehensive model through the consideration of numerous realistic global factors. In addition to transfer prices, they examine special cases of facility location models in which government financing, tax incentives, local content requirements (LCRs), and regional trading agreements are present. The goal of their model is to maximize after-tax profits through the design of an optimal network of plants and DCs for a firm using a hybrid product-process focus. A numerical example is provided, depicting a firm with expected demand from markets around the world. Six cases are modeled, showing the effects of financing, tariffs, local content, regional trading zones, and taxation. With their all-encompassing model, Kouvelis et al. [41] provide the reader with many realistic situations to which their model applies, assisting decision makers in choosing optimal facility locations and demand allocations under varying circumstances.

Robinson and Bookbinder [63] (2007) examine DC and finishing plant locations for a firm operating in the NAFTA region. Their multiperiod model also determines the flow of material and transportation mode to employ when shipping goods within Canada, the United States, and Mexico. Because distribution is contained within the NAFTA region, tariffs are negligible and border-crossing costs are included in transportation costs. The authors find that capacity will ultimately determine the degree of centralization of finishing plants and DCs in the system, additional facilities will be added to the network if demand exceeds capacity, and that more than one mode of transportation is necessary when there is insufficient lead time.

Take-or-pay costs are incurred when buyers must pay for the total contracted volume of a shipment, even though that quantity may exceed the actual demand. Hamad and Gualda [33] (2008) incorporate this concept and other traits, such as value-added taxes, in their location model. The authors then apply it to a firm in the chemical industry based in South America with worldwide operations.

We note that all mathematical models in this section assume deterministic conditions, perhaps due to the strategic nature of the decisions being made. We would anticipate that over a long time horizon, parameters that are subject to fluctuations (i.e., exchange rates, tariffs, and duties) will assume their expected values, and that employing random variables would only complicate the model. If random variables were considered, this would increase
the difficulty of solving the problem, and the effort required to obtain representative data may not contribute any additional insight.

Although many of these models solve location and allocation decisions simultaneously based on a number of quantitative and qualitative parameters, region-specific characteristics such as LCRs, free trade agreements, and value-added taxes are examined by only a few articles (e.g., Kouvelis et al. [41] 2004, Robinson and Bookbinder [63] 2007, Hamad and Gualda [33] 2008).

4. Procurement

In a typical procurement or sourcing problem, a firm wishes to purchase, from one or many suppliers, components or raw materials and have them delivered to their various facilities. The selection of suppliers will depend on purchasing cost and the ability of the supplier to meet the firm’s demand. An international sourcing problem tackles additional challenges that arise due to the risks that may be involved. Diversification of a supplier network can result in many advantages, such as competitive prices and higher quality, but a firm may incur increased costs when transporting goods from farther away when fluctuations in exchange rates affect purchase prices of goods, or when paying duties and tariffs on imported components. There are few papers that address the supplier selection problem in an international context, as seen in Table 4 and concurrent with the findings of Meixell and Gargeya [50] (2005).

Gutierrez and Kouvelis [31] (1995) provide the reader with both deterministic and stochastic models whose solutions are robust. The deterministic model generates different scenarios that reflect fluctuating exchange rates and inflation. These solutions are then used as input for the stochastic model, eliminating the need for managers to assign probabilities to multiple exchange rate scenarios. The robust nature of the models makes them insensitive to these fluctuations, and still able to generate a solution that is nearly optimal. In contrast, Gonzalez Velarde and Laguna [26] (2004) incorporate exchange rates explicitly in their robust model by generating a table of scenarios for weak, medium, and strong international economic regions and good, average, and bad economic states. Their mixed integer nonlinear program is solved using a heuristic based on Benders decomposition and tabu search.

Munson and Rosenblatt [55] (1997) examine the effects of LCRs on supplier selection from several countries. They model a single plant situation with one local content rule in a deterministic environment and find that the firm will source at most one component from two different suppliers. This model can accommodate additional LCRs in a multiplant situation, though the authors note that if some components were produced in-house or obtained through local suppliers, the computational difficulties would be lessened.

Balaji and Viswanadham [4] (2008) develop a tax-integrated model to determine whether it is in a company’s interest to outsource material or pursue foreign direct investment (FDI). They consider an eight-stage supply chain for the manufacture of computers, with operations in two countries. To incorporate tax planning in their model, the authors include the tax incurred per tax lot of transferred goods as a parameter. A hub-based model is also proposed, where firms may source their components from a regional hub and benefit from lower taxes, lower costs, and higher-quality freight handling. In their numerical example, Balaji and Viswanadham [4] show that it is optimal to outsource production to the country where cost is lowest, even when demand exists in both countries. It is also in the company’s best interest to outsource production when demand is high and to use FDIs for echelons closest to the customer.

Few publications deal with procurement in a global setting. We discussed several of those articles and noted that a variety of factors were considered in each of them. Exchange rates, LCRs, and taxes have been incorporated in the development of sourcing policies to meet the requirements set by the decision makers. In contrast to the deterministic facility location...
Table 4. Procurement models.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Model type</th>
<th>Objective</th>
<th>Time period</th>
<th>Number of products</th>
<th>Transfer prices</th>
<th>Exchange rates</th>
<th>Duties and tariffs</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gutierrez and Kouvelis [31]</td>
<td>1995</td>
<td>St</td>
<td>Min cost</td>
<td>S</td>
<td>S</td>
<td></td>
<td>*</td>
<td>✓</td>
<td>Model deals with uncertainty in cost only, not demand</td>
</tr>
<tr>
<td>Munson and Rosenblatt [55]</td>
<td>1997</td>
<td>D</td>
<td>Min cost</td>
<td>S</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>Can incorporate multiple LCRs</td>
</tr>
<tr>
<td>Gonzalez Velarde and Laguna [26]</td>
<td>2004</td>
<td>St</td>
<td>Min cost</td>
<td>S</td>
<td>S</td>
<td></td>
<td>✓</td>
<td></td>
<td>Solution method is a heuristic based on Benders decomposition and tabu search</td>
</tr>
</tbody>
</table>

Notes. All models in this subset assume deterministic conditions. D, deterministic; St, stochastic. S, single; M, multi.
*Implicitly considered.
models examined in §3, the optimality of a procurement network will depend heavily on
the realized values of the random variables considered. The most prominent of these are the
exchange rates. Considerable importance is thus placed on choosing appropriate scenarios
for use in the corresponding stochastic program.

5. Transportation

5.1. Introduction

In addition to facility location and supplier network decisions, a well-defined transportation
plan is necessary to ensure an optimal flow of material throughout the supply chain. Unfor-
tunately, transportation is sometimes the forgotten element in a supply chain model. Nodal
activities, such as fabrication, assembly, and inventory, are emphasized when the focus is
on conversion of components to subassemblies and finished products. But how do those
materials actually get from one node to the next? Can the timing or scheduling of those
movements of goods be improved? Can the flow be accomplished at lower costs?

We feel that transportation should be accorded the same importance as the other oper-
ations management activities. The benefits of good production-inventory decisions can be
easily overwhelmed by neglecting the economies of scale available in the various transport
modes.

Two of those modes, air and water, are the only ways to move goods between noncon-
tiguous countries. Water transportation and air freight are automatically “global” in that
context. Useful references include Groothedde et al. [29] (2005) and Chang [17] (2008) on
international shipments by water and air, respectively.

In this section, we will limit consideration to papers whose major focus is transportation,
but within global supply chains. Morash and Clinton [54] (1997) have studied empirically the
general impacts of transportation in those cases. There is of course an extensive literature
on the international transport of goods. The subset of interest to us consists of articles in
which the shipments are part of an overall supply chain model for the analysis of purchasing,
manufacturing, or distribution.

5.2. Transportation by Road or Rail

Once a network of facilities and suppliers is established, the flow of goods between these
locations and the mode by which they travel must be determined. A transportation model
seeks to minimize the cost, distance, or time associated with transporting goods from their
origins to destinations by making appropriate modal choices.

Intermodal transportation occurs when a product is shipped using two or more different
modes. For example, a shipment from a supplier in Hong Kong may travel to California by
ocean, and then be transloaded from the vessel onto a truck, where the remainder of its
journey to various DCs will be by road. Intermodal transportation stresses the systematic
transfer of such goods between different modes to minimize handling and downtime (Gourdin
[27] 2006). In a global context, transportation is inevitably intermodal: products will be
transferred at a port from vessel to rail, or at an airport from plane to truck. The land
routes between the NAFTA countries are somewhat unusual in permitting international
intermodal shipments by truck and rail.

Bookbinder and Fox [9] (1998) analyze the flow of material in the NAFTA region, specif-
cically from Canada to Mexico. The authors develop potential intermodal routes from five
Canadian cities to three Mexican cities and show that shipments from central Canada are
the most direct, regardless of the destination city. Also, they observe that coastal origins
require more efficient intermodal combinations. Potential future service expansion could
include a link by water between Vancouver and Manzanillo, a port on the west coast of
Mexico, as well as a direct rail link between Calgary and El Paso, Texas.
Most “regional” models concern the logistical activities within a given free trade zone, for example, flows from Canada to Mexico in a NAFTA supply chain. McCray and Gonzalez [48] (2008), however, have noted that those two countries could play a wider role because of acute capacity shortages and occasional labor disruptions at American West Coast ports—international shipments, destined to the United States, might take advantage of the NAFTA relationship. Intermodal terminals on the Pacific coast of Canada or Mexico would require an expanded infrastructure. Only then would transit through those ports enable container shipments to bypass the possible bottlenecks in California or Washington.

European rail service is at a crossroads. Environmental concerns and the fully exploited capacity of the road network strongly indicate greater use of rail–truck intermodal transportation. The EU thoroughly advocates this. There is now generally also a distinction in each country between the national ownership of a track and the right to operate rail services on that track.

With the EU’s enlarged membership now incorporating 27 countries, including some in Eastern Europe, there is potentially a new north–south corridor on which rail intermodal service could expand. Nair et al. [57] (2008) assess the market potential for this. Kuo et al. [42] (2008) recommend that this expansion be facilitated by the collaboration of multiple rail carriers on what is termed the REORIENT corridor (11 countries, southward from Scandinavia to Greece). The mechanism proposed by those authors is that of “train-slot cooperation.” Furthermore, Janic [36] (2008) suggests that long intermodal freight trains (LIFTS) be operated as a block within Europe, potentially through this same corridor.

5.3. Transportation by Air

Warsing et al. [76] (2001) study the economic benefits of using a dedicated multimodal cargo facility (DMCF) as opposed to a traditional passenger-based airport. These authors seek to minimize delays that result from congestion in the flow of materials. The DMCF acts as a hub, where a firm can locate some of their logistical activities (e.g., warehousing, production/distribution) closer to the cargo handling and transfer facilities, minimizing the amount of disruption in material flow that would normally occur otherwise. The model consists of a network of regions, each with demand destinations and supply points. The latter act as transshipment points for interregional shipments; each supply point also serves customers within its own region. The objective is to minimize total transportation costs by deciding the quantity of products to ship to customers, the aircraft by which products will travel, and the amount of inventory at each customer’s facility at the end of the period. The authors assume that there is a significant distance between each region that requires interregional shipments to go by air, there is a limited number of aircraft available in each region, and that the products require “same-day” delivery. To calculate the shipping lead time, a queueing approach is used to determine the successive waiting times experienced between the manufacturer’s dock and the product’s interregional departure, and then to the product’s arrival. Warsing et al. [76] determine that using a DMCF can help reduce delays in material shipment and decrease holding costs compared to those at a nondedicated facility.

Tyan et al. [71] (2003) also take a multimodal approach to global transportation, but from the view of a third-party logistics provider (3PL) that must make decisions regarding consolidation of material and select alternative flights for shipment. In this model, the 3PL must consolidate the manufacturer’s orders (loose cartons or skids of 40 cartons) in a way that will minimize costs without compromising customer service. Tyan et al. [71] propose three consolidation policies, where physical consolidation of material takes place at both cargo and express terminals. Policy differences relate to degrees of just-in-time (JIT) and cost–service trade-offs. Their findings, consistent with other studies of shipment consolidation in a nonglobal context, suggest that collaboration between 3PLs and shippers will benefit both parties. Customer service performance can improve, and total costs decrease, when the 3PL may exercise some consolidation decisions.
Chang [17] (2008) proposes a multiobjective, multicommodity flow problem to determine optimal routes for an international intermodal carrier. His model comprises three essential yet complicating characteristics of intermodal routing: (1) the multiobjective nature of the problem, because shippers may want to minimize costs and/or travel time; (2) scheduled transportation modes and delivery times to ensure feasible routes are being considered; and (3) the effect of economies of scale on transportation cost. To solve the model, the authors apply Lagrangian relaxation techniques and decompose the problem into two subproblems: one to minimize travel time and cost of material flow, and the other to minimize travel cost for flow within a specified range. Once a solution is found, the problem is reoptimized to ensure the final solution is feasible. Chang [17] provides the reader with a numerical example for a distributor of LCD monitors, shipping from Taiwan to the United States.

Additional references include Neiberger [58] (2008) on European air freight shipments, and Huang and Chi [34] (2007). The latter authors approach the consolidation problem faced by air freight forwarders by initially transforming it to a set covering problem: a feasible consolidated shipment is treated as a set. Lagrangian relaxation is employed in a heuristic algorithm.

5.4. Other Transportation Models

Erera et al. [23] (2005) study the movement of intermodal tank containers used in the chemical industry. A tank container operator must manage a fleet of containers as they travel by road, rail, and/or sea, and must take into account that most customers are requesting one-way trips to get their order from point A to point B. To improve utilization of these tank containers, the operator should be aware of the imbalance in shipping patterns, where certain regions, such as North America, tend to be net sources of containers, whereas others, such as East Asia, tend to be net sinks (see McCalla et al. [47] 2004). Empty repositioning helps to correct the geographical and temporal imbalances by moving these empty containers between depots. The authors develop a deterministic multicommodity network flow model to find the optimal routing of empty and loaded containers that will minimize total transportation and depot costs. A computational study is performed to examine the effects of three strategies: (1) weekly repositioning, where depot-to-depot repositioning is allowed only on the first day of the week; (2) bounded daily repositioning, where depot-to-depot repositioning is allowed every day, but if this option is exercised a lower bound is imposed to deter numerous small shipments from being made; and (3) unbounded daily repositioning, where repositioning is allowed every day with no restrictions. The authors find that Option 3 provides the lowest cost, because timing has more of an impact on total cost than does the number of containers to reposition.

Groothedde et al. [29] (2005) propose a hub-based network for intermodal transportation. Trucks deliver products from the manufacturer to the hub, and from the hub to the product’s final destination; barges are used for interhub transportation in this application in The Netherlands. The general hub network design problem is relaxed so that not all hubs are interconnected, direct shipment of material between facilities is allowed, and facilities can be assigned to more than one hub. In their model, the authors seek to minimize total transportation cost by determining the optimal location of hub facilities, the assignment of origin and destination facilities to the hubs, linkages between hubs, and the flow of material through the network. The hub network allows for economies of scale through the consolidation of material traveling between hubs, offsetting extra costs incurred from increased shipping distance. Because transportation by sea is slower than by truck, well-forecasted demand should be shipped by barge through the hub network, whereas unpredictable demand should be transported directly by truck from origin to destination. In this way, customer service is not jeopardized, and firms can take advantage of lower shipping costs. Groothedde et al. [29] propose that further collaboration between firms, such as sharing resources and information, can lead to benefits for both parties.
6. Production Switching, Transfer Pricing Policies, and Postponement

With the implementation of optimal transportation policies, the nodes in the supply chain are linked by air, water, rail, and road. In §§3–5, we examined the decisions that a company considers when developing its global supply chain. In this section, we focus on the production of material in an established logistics network. A company with facilities located worldwide will inevitably encounter fluctuations in demand, exchange rates, and production costs. Depending on the direction of these variations, it may at times be more profitable to produce in only one, all, or a combination of some countries. The papers in §6.1 address the issue of production switching, when companies must evaluate whether moving production to a location with lower wages and a more competitive exchange rate will offset the setup costs associated with this shift.

Another important issue in international supply chains is transfer pricing. When divisions within an MNC transact with one another, a transfer price set by the MNC is charged by the selling division to the buying division. Because this price will affect profits and expenses reported by each business unit, and with the incorporation of varying exchange rates, it is important to set an appropriate transfer price that adheres to government regulation. The papers in §6.2 include transfer pricing in their models to evaluate its effect on production scheduling and company profits.

In §6.3, we address the concept of postponement. Rather than transfer the complete production of an item between two or more facilities, a postponement strategy allows the firm to manufacture a generic product at a number of its facilities. The items are then shipped to their respective destinations where further value-added processes may take place to customize the goods.

6.1. Production Switching

Kogut and Kulatilaka [39] (1994) present a model to assess the value of having production facilities in two different countries. As exchange rates fluctuate, to which country should a company shift production to minimize their costs? The authors develop a model to determine the number and location of facilities while considering variability in real exchange rates. This decision is complicated by a number of costs associated with production shifting, such as shutdown, start-up, and transportation costs. In general, a plant should be built if the value of its flexibility exceeds the initial investment required.

Huchzermeier and Cohen [35] (1996) also examine the value of production flexibility for an international firm by using a hierarchical approach. First, the authors model exchange rate fluctuation, then the firm’s global manufacturing strategy is used to determine potential product and supply chain network designs, and finally, switching costs are studied. Huchzermeier and Cohen [35] develop a stochastic dynamic program that examines different exchange rate scenarios to determine the number and location of facilities as well as the allocation of demand. A subproblem is also solved to calculate the optimal quantities of product shipped from suppliers to plants and plants to markets to optimize after-tax profits.

Unlike Huchzermeier and Cohen [35] (1996), Dasu and Li [22] (1997) propose a deterministic model, as they consider the long-term value of locating facilities internationally and using excess capacity to hedge against variability. The authors present a model for two facilities located in two different countries, and determine the optimal amount and time to produce to minimize costs when the firm is subject to switching costs and exchange rates. This model is then extended to consider $n$ countries, as well as a firm that serves multiple markets. Dasu and Li [22] prove that, when switchover costs can be modeled as linear or stepwise functions, regardless of the number of markets that the firm serves, the optimal policy is always the barrier policy; i.e., either the upper or lower barrier specified in the available options will be the optimal policy.
Mohamed [53] (1999) studies the effects of varying inflation and exchange rates on an MNC’s operational decisions. In this model, the author determines the products to produce at each facility, and the market that this facility will serve to minimize total costs. A detailed description of relevant costs is provided. In numerical examples, the author finds that the total number of units produced and the required capacity for a facility are independent of the exchange rate variation, and that the highest profit is made when companies begin with optimal capacities. Mohamed [53] also examines the sensitivity of profit to the exchange rates when there is a capacity limitation.

Li et al. [43] (2001) propose a stochastic control model to decide which facilities to operate under varying exchange rates and uncertainties in demand. The authors consider a two-country production network that produces a single product and allows backlogging for those orders that are not met. Their results show that for an exchange rate below the intersection of the two switching cost curves, the primary facility is the overseas plant, and the secondary facility is the home plant. When inventory is sufficiently high, neither plant is operated, but as inventory drops, the overseas unit will begin operations, followed by the home plant. When the exchange rate is above the intersection of the two switching curves, the scenario is reversed, as the home plant and the overseas plant become the primary and the secondary facilities, respectively. Li et al. [43] extend their model to consider multiple plants in each of the two countries and in multiple countries.

To manage production when facing exchange rate uncertainty, Kazaz et al. [38] (2005) propose the application of two operational hedges. As managers receive new information throughout the production period, these hedging strategies allow for adjustments to the production plan that either react to (allocation hedging) or act in anticipation of (production hedging) varying exchange rates. The problem is divided into two stages. The firm must decide (1) how much to produce to satisfy demands in two different markets and (2) how much of that production to allocate to each market. The objective is to maximize the firm’s expected profits subject to transportation and demand constraints. Kazaz et al. [38] extend their single-period model to a multiperiod scenario and find that, in each of these cases, the optimal solution applies both allocation and operational hedging. The authors also examine the effect of uncertain demand, the timing of price-setting decisions, and their combined effect.

Wu and Lin [78] (2005) also consider exchange rate uncertainty in their entry–exit decision-making model. The model consists of a single exporter that must determine the optimal entry or exit threshold value at which domestic production should be transferred overseas, subject to real exchange rates and their volatility, tariffs, wages, and prices of raw materials. The objective is to maximize the value of the exporter’s products through the optimization of the quantity of raw materials and labor required.

6.2. Transfer Pricing Policies
Kouvelis and Gutierrez [40] (1997) incorporate transfer prices and exchange rates into their two-market global newsvendor problem, obtaining the optimal quantities of items to ship from the primary market to the secondary market and the production quantities to be produced by the secondary market. The decisions to be made are from the viewpoint of the corporate planner, who must consider shortage costs attributed to lost sales and overage costs attributed to selling items at their salvage value at the end of their selling season.

Kouvelis and Gutierrez [40] also examine a decentralized policy, where each division of the firm is responsible for making purchasing and production decisions. This arrangement allows the divisions to act independently but requires more coordination in deciding the transfer prices applied to goods shipped between divisions. In cases where transfer prices are constant across the firm, this could lead to suboptimal policies, so the authors suggest that “more sophisticated transfer pricing mechanisms” be used (Kouvelis and Gutierrez [40] 1997). These mechanisms include firm-controlled transfer prices, when a constant and
agreed-upon price is applied to shipments between profit centers, and intermediate purchasing coordination. This latter mechanism imitates a centralized transfer pricing policy on a smaller scale, because one of the firm’s centers is responsible for coordinating the trade of goods between two of the firm’s other profit centers. This allows each of the units to act independently while maximizing the overall profit of the firm.

Vidal and Goetschalckx [74] (2001) formulate a model to assist MNCs in setting transfer prices that will maximize their net income after tax, as well as ensure that the performance targets of each division are met. In addition, their model decides how transportation costs should be allocated, the transportation mode employed on each arc, and the quantity of material to ship from one plant or DC to another. The authors make a distinction between internal and external suppliers: transfer prices do not apply to the latter case, but rather market prices will influence how much those suppliers will charge the MNC.

Miller and de Matta [52] (2008) develop a global profit maximization plan that determines the optimal production policy for each plant in the firm’s network, as well as a sourcing and distribution plan with associated transfer pricing policies. Their model maximizes profit while considering tax and exchange rates in each country and the lower and upper bounds on transfer prices applied to intramarket and market-to-customer transactions. The nature of this model is such that it can be used for tactical or strategic production planning, because the firm can evaluate the robustness of the plan and adjust it as necessary in the short run or analyze the effect of exchange rates on the plan over a number of years.

Villegas and Ouenniche’s [75] (2008) model seeks to maximize the profit of an MNC with a thorough consideration of many global factors, including exchange rates, tariffs, duty drawbacks, income tax rates and credits, royalties, and transportation costs. The model determines the optimal quantities of the products to produce and sell for each division of the firm, the allocation of transportation costs to each division, and the associated transfer prices. The results of this model suggest that optimal transfer pricing and transportation cost allocation policies occur at their upper or lower bounds when there is a low level of exchange rate risk, and that trade quantities and transportation cost allocations do not affect transfer prices.

6.3. Postponement

Hadjinicola and Kumar [32] (2002) examine eight different manufacturing and marketing options for a firm producing in two countries. The options consider the degree of customization and centralization of the firm, as well as the prevalent production policy. Core production options, referring to the manufacture of a core product in one of the two facilities, dominate the other strategies, because the firm achieves economies of scale and still has the flexibility to customize the product further along its supply chain.

Yang and Burns [79] (2003) identify the decoupling point, degree of demand uncertainty, costs, and capacity requirements as the main components of the existing supply chain that will be affected by a postponement strategy. In a later article, Yang et al. [80] (2004) propose a framework to determine whether adopting postponement is ideal based on the reliability of demand forecasts, nature of the organizational culture and structure, and the degree of flexibility in other areas of the supply chain. Yang et al. [79, 80] have outlined a number of general principles on postponement that are clearly applicable in the global context.

Employing postponement may influence the proportion of locally and globally sourced components. Jin [37] (2004) determines that understanding the nature of demand, importance of information and manufacturing technology, vicinity of subcontractors, and relationships with suppliers will help to achieve a balance in the sourcing policy that maximizes profits.

Prasad et al. [61] (2005) conduct a survey, comparing make-to-stock (MTS) and build-to-order (BTO) supply chains in developed and developing countries. The authors conclude that BTO systems are preferable when there is uncertainty in demand, requiring individual
items to be tracked along the supply chain to ensure the customers’ requests are satisfied. Developing countries generally have less reliable lead times and tend to employ coordinated replenishment policies for cost savings, resulting in an environment more conducive to an MTS system.

The models in §§6.1 and 6.2 are perhaps the most mathematically involved because they account for the variability of global economic factors. As companies strive to meet their performance targets, there is a growing importance placed on developing and implementing appropriate transfer pricing and production switching policies that maximize profit for each division of an MNC. Furthermore, the implementation of postponement on a global scale can influence the policies of the firm due to challenges stemming from demand uncertainty and differences in organizational processes and practice.

7. Overall Network Design

Previous sections discussed each functional area of the supply chain on its own. The papers below assimilate these functions into one strategic model that can be used to optimize an entire logistics network, deciding optimal facility locations, product-sourcing and manufacturing plans, and transportation flow. Compared to papers discussed previously, these models have a greater scope, and hence are able to incorporate many global features (as in Arntzen et al. [1] 1995) and specific aspects of regional trade (as in Wilhelm et al. [77] 2005).

Arntzen et al. [1] (1995) develop a comprehensive model for the Digital Equipment Corporation supply chain that determines the production plan and location of facilities and the quantity of products to produce and ship. Inputs to the model include the global BOM, demand, LCRs, and a variety of costs. Arntzen et al. [1] use an objective weighting factor to integrate both time and costs in the objective function. The scope of this model has allowed those authors to apply it to a variety of studies involving sourcing and distribution decisions, revision of manufacturing infrastructure, and repairs and service improvements.

Camm et al. [12] (1997) incorporate a geographic information system (GIS) in their overall supply chain model for Procter and Gamble. The problem is decomposed into a distribution-location model and a product-sourcing model. The visual interface of GIS allows users to identify sets of optimal sourcing solutions by inputting product type, potential plant locations, and transportation modes. The output there can in turn be employed as input for the product-sourcing model, which is then used to obtain the optimal manufacturing-distribution plan.

Dasu and de la Torre [21] (1997) examine a network of partially owned and affiliated textile facilities in Latin America. The corporate firm faces competition from the external market, but because the affiliates operate in the same region and independently of one another, any intrafirm competition could potentially hinder the overall performance of the MNC. Depending on the level of collaboration between the firms, the optimal pricing policies for the firms will vary. To capture the dynamics of the MNC’s profits, the authors develop a model that fosters intrafirm cooperation when each of the firms faces direct external competition, and another that examines intrafirm rivalry. Each model seeks to maximize profits by calculating optimal sales prices and quantities for each firm.

Tsiakis et al. [70] (2001) examine an entire global supply chain network where decisions need to be made regarding the number, location, and capacity of warehouses and DCs, the allocation of demand, and the production rate and shipment quantities of material to minimize cost. The authors apply their model to two case studies, where demand is deterministic and then uncertain.

Sheu [67] (2004) uses a fuzzy AHP in combination with the fuzzy multiattribute decision-making (MADM) techniques to help identify global logistics strategies for companies. This model is useful in realistic situations where conditions are uncertain or vulnerable to risk,
allowing users to subjectively rank decision alternatives according to specific performance criteria, thus generating an optimal solution that meets the requirements of decision makers.

Contesse et al. [19] (2005) model the purchase and distribution of natural gas in South American countries. Their MIP assists a Chilean firm in deciding optimal volumes of natural gas to purchase from a selection of suppliers and the method of transport. The model is intended for operational planning, allowing the user to update the model daily or as demand information becomes known with certainty. The authors extend their deterministic model by developing a robust optimization approach to consider demand-varying scenarios.

Nagurney and Matsypura [56] (2005) examine the effect of risks and uncertainty on a global supply chain network. A three-tier supply chain is considered where electronic orders are allowed, meaning that retailers have a direct link to their manufacturers, essentially bypassing the distributors. There are risks associated with each tier, such as political and exchange rate risk for manufacturers and distributors, or demand uncertainty for retailers. In light of this, the authors have developed a multicriteria model such that the objective is to minimize risk and maximize profit. Goh et al. [25] (2007) present a similar model, considering the variability in exchange rates, tariff rates, tax rates, and market demands. That model suggests the optimal number of facilities to open or shut and the quantities of product to ship to customers.

Santoso et al. [65] (2005) use the sample average approximation strategy to handle the stochastic nature of particular variables in their supply chain network model. They choose as random variables the transportation and processing costs, demand, supplies, and capacities. The model determines which processing centers to build, which processing and finishing machines to procure, and the routing of products from suppliers to customers. The objective is to minimize the current investment costs and expected future processing and transportation costs.

Wilhelm et al. [77] (2005) present an intricate model specific to the NAFTA region. The model considers a multitude of variables to capture the reality of international supply chains. To maximize after-tax profits, the firm must decide the amount of material that is backordered, the number of components that are shipped or held in inventory, by which mode the products will be transported, and the associated transfer prices. Influencing the decisions are costs (fixed, transportation, backorder, and material), capacity, tariffs, tax rates, LCRs, BOM restrictions, income taxes, and exchange rates. The model is applied to 11 different cases, examining the effect of centralized/decentralized decision making, outsourcing versus in-house assembly, flexible versus dedicated technologies, and economies of scale versus economies of process.

The preceding models consider many global factors and characteristics in the development of optimal overall supply chain networks. Although LCRs, BOMs, and exchange rate variations are typical in any international manufacturing setting, we note that only Wilhelm et al. [77] (2005) present a model specific to a free trade zone (NAFTA). Other models consider general trade situations between international partners and do not encompass some of the particular traits of a given free trade agreement.

8. Other Papers

The literature review thus far has concerned normative models only. In this section, we summarize several empirical studies that have been done, relating to global logistics and transportation. These studies employ a variety of data collection methodologies to gain additional insight on a number of international situations, such as the effects of globalization, reasons for and against expanding sourcing networks, and comparisons of regional logistics practices. Our discussion is organized by the type of data used to analyze these issues. Although the technicalities of empirical research are not the focus of this study, we do note some general observations from our own experiences and the articles cited in this section.
8.1. Cross-Sectional Data
Well-structured surveys, questionnaires, or personal interviews offer informative answers to aid in a researcher’s study. The two former options are less intrusive and usually require less time to complete, whereas the latter can be used to elicit higher-quality answers that may shed light on otherwise ambiguous topics. These methods, however, typically examine issues at a cross-section in time, and are therefore widely used for comparisons and identification of areas for further research.

Lynch et al. [45] (1994) conduct a Delphi study to forecast the future of logistics in Canada based on responses from industry experts. Their survey contains seven sections: international, transportation, industry, logistics managers, environment, government, and technology, whose conclusions must be forgiven the 15 years’ experience since then.

Bolisani and Scarso [8] (1996) carry out a survey of Italian clothing firms to determine what factors influence the internationalization of these organizations. The authors find that most companies are driven to reduce costs by locating their facilities closer to customer and supplier markets, and by seeking lower-wage but highly skilled labor. To maintain the same level of profitability, these firms generally prefer centralized coordination, where the head office is actively involved in ensuring each that division meets the corporatewide goals.

Das and Handfield [20] (1997) investigate the feasibility of using JIT sourcing at a global level. The authors survey North American firms that have either domestic or global suppliers, some of which are JIT suppliers. In their research, the authors find that domestic JIT suppliers and global non-JIT suppliers tend to provide superior product quality over their counterparts, whereas all JIT suppliers provide more reliable and frequent deliveries. Firms that transition from domestic to global JIT suppliers will realize a reduction in supplier costs; however, the reverse is true for non-JIT suppliers.

Morash and Clinton [54] (1997) study the differences in transportation capabilities between firms in the United States, Korea, Japan, and Australia. Their survey focuses on seven areas related to transportation logistics in industry: time compression, reliability, standardization, JIT delivery, information systems support, flexibility, and customization. The authors find that both American and Japanese firms place a higher importance on the reliability of transportation logistics than any of the other dimensions. Korean firms are more likely to improve their information support systems and prefer a centralized management style, whereas Japanese firms will focus their efforts on integrating their external supply chain with the internal activities. Whereas Japanese firms have more formal relationships with their partners, Australian and U.S. firms will take a more interactive approach, sharing information and resources with their customers and making site visits more frequently.

MacCarthy and Atthirawong [46] (2003), similar to Lynch et al. [45] (1994), use the Delphi method to survey members from academia, the government, and consultancies about factors affecting location decisions in global supply chains. In the first part of their study, the authors find that access to low labor costs and highly skilled labor are major motivations for companies when determining facility locations. In the second part, the influencing factors developed by the panelists are ranked, with costs, infrastructure, labor characteristics, government and political factors, and economic factors being the five most important for decision makers to consider.

Steenhuis and De Bruijn [68] (2004) develop an assessment tool to support facility location decisions. Using the gross domestic product (GDP) per working person and knowing the nature of the industry, companies, as well as regional governments, can assess the feasibility of having a firm locate one or more of its facilities in their area.

McCalla et al. [47] (2004) examine the differences in containerization between North America, Europe, and East Asia. In terms of geography, because North America is much larger and continental, rail is the predominant mode of choice for long-distance transportation, whereas there is a tendency in East Asia and Europe to use water transport. Differences in economic development lead to imbalances in imports and exports: because North America
imports more than it exports, a large number of empty containers eventually build up, whereas the opposite is true for East Asia. Institutional constraints also affect the reliability and service that companies are able to provide in each area. In North America, containerized shipments are now subjected to security inspections at the border, following the “10+2” initiative. An importer security filing is sent to U.S. Customs and Border Protection prior to the container’s physical arrival at the border, comprising 10 elements of information pertaining to the importer, seller, buyer, manufacturer, and consolidator of the shipment. Two additional pieces of information that can also be provided are the vessel stow plans and container status messages (U.S. Customs and Border Protection [72] 2009). The result will still be less delay than in Europe, where some delays exist because of mandatory locomotive switching and crew changes enforced at the country borders. High levels of bureaucracy in East Asia make delays unavoidable because intermodal transportation of goods does not hold as much priority as passenger transport.

Carbone and Stone [16] (2005) focus on growth and relational strategies of 3PLs in Europe. Through personal interviews, examination of annual reports, press, and quality reviews, the authors show that mergers and acquisitions are commonly used by 3PLs to be able to serve a larger geographic market and to take advantage of economies of scope and strategic synergies. Relational strategies are also used to develop vertical or horizontal alliances. A vertical alliance involving 3PLs and their customers can put the 3PL at risk if there is too much dependence on a given customer for continued business. In contrast, a horizontal alliance involves only 3PLs, allowing costs and risks to be spread out among the firms.

8.2. Case Studies

Typically, a case study examines a problem faced by a particular company or industry over a certain period of time, where some of the relevant data are obtained through secondary sources. We find, however, that many of the case studies we examine have supplemented their initial data collection with unstructured interviews or site visits, providing more meaningful information for analysis. These studies, compared to the cross-sectional data studies above, tend to seek answers to more specific problems and are able to draw more definite conclusions pertaining to the effects of certain initiatives on a single firm or an industry.

Robertson et al. [62] (2002) conduct a case study of a steel manufacturer serving firms in Australia, New Zealand, and Southeast Asia. The authors detail how a “global sales and operations optimizer” is synchronized with the master production schedule, achieving effective coordination of information, and resources across the tiers of the supply chain.

Meijboom and Voordijk [49] (2003) approach globalization from a different angle, interviewing companies in The Netherlands to find out why they have opted to maintain a regional presence despite the growing trend to internationalize. The authors discover that the political and economic environment of the domestic region and proximity to the consumer market persuade companies to remain in Western Europe.

Liu and Young [44] (2004) develop an information technology model to coordinate manufacturing decision making. Their model is integrated with two existing information models to allocate production tasks, support producer/consumer relationship coordination, and ensure that all manufacturing activities are synchronized.

Buxey [11] (2005) interviews senior executives of Australian textile, clothing, and footwear (TCF) firms to examine how these industries have responded to globalization. The author identifies six different strategies used by the three industries: low cost, market access, global, defender, importer, and exporter.

Stratton and Warburton [69] (2006) examine the implications of outsourcing in three case studies. The authors find that in each case, as companies transition to offshoring to take advantage of reduced production and labor costs, difficulties arise in the reliability of the new suppliers and increase in lead times. The authors suggest that those trade-offs in outsourcing should be explicitly considered when evaluating the option to source abroad. This proactive
approach may ease the transition to outsourcing and avoid any inconsistencies in expected savings and performance.

Rudberg and West [64] (2008) detail a case study for coordinating manufacturing networks. The “model factory” concept provides standardized guidelines to show the best possible network of factories. Using this network, responsibilities are assigned to each plant, and competence groups are established to ensure continued information sharing and knowledge transfer.

These empirical studies establish useful foundations for normative research, because the knowledge and insight gained from personal interviews and questionnaires can help create models more applicable to specific industry problems. From the issues studied, we see that regional differences account for many of the challenges encountered in global logistics. Language, regulations, geography, and local customs are all factors that affect the efficiency of production, transportation, and marketing in a given international supply chain. Researchers encourage streamlining processes and sharing meaningful information to improve supply chain coordination.

9. Regional Models
Although the majority of papers in our review apply to global logistics in a general sense, there are a number of models that deal with variables and constraints that are unique to specific regions. Below we highlight characteristics of four normative regional models. Others include Badri [2, 3] (1996, 1999), Dasu and de la Torre [21] (1997), Dasu and Li [22] (1997), Tsiakis et al. [70] (2001), Tyan et al. [71] (2003), Santoso et al. [65] (2005), Robinson and Bookbinder [63] (2007), and Hamad and Gualda [33] (2008).

9.1. North America
Wilhelm et al. [77] (2005) include a number of NAFTA-specific constraints in their network model. For a laptop manufacturer with suppliers in the United States, Mexico, and China, the authors present 11 cases to model the key logistics decisions. The constraints include LCRs that are imposed on components moving within the NAFTA region, upper and lower bounds on transfer prices, border-crossing costs, and transportation cost allocations. The safe harbor rule is also modeled to account for the tax credit that will be received by an eligible maquiladora (generally, a labor-intensive plant in northern Mexico).

9.2. South America
Contesse et al. [19] (2005) include take-or-pay costs in their MIP model, which are also seen in Hamad and Gualda [33] (2008). The buyer is required to pay this amount for a contracted volume of natural gas, regardless of customer demand. Penalties against the buyer apply if daily minimum purchase levels are not met, or maximum levels are exceeded. The contract entered into by the supplier and buyer is such that it persuades the buyer to maintain a high purchase volume. The model of Contesse et al. [19] considers the flow of natural gas from suppliers in Argentina to a distributor in Chile and accounts for the lack of storage facilities, a problem that is not normally faced in North America, as the authors mention.

9.3. Europe
Groothedde et al. [29] (2005) develop a hub network based in The Netherlands and connecting to Germany and Belgium. Though the authors do not explicitly discuss regional trading practices or incorporate international constraints, as seen in Wilhelm et al. [77] (2005), they do create a model that recognizes common shipping practices in Europe. Transportation by inland waterway is paramount in their model, a feature that is distinctive in Europe but not as widely available in continental regions, such as North America.
9.4. Asia and Australia

Sheu [67] (2004) captures the current trends in Asian logistics, having based his model on a survey of Taiwanese manufacturers. The model compares six global logistics strategies typically employed in the integrated circuit industry, using a fuzzy AHP and fuzzy MADM to determine which strategy is best for a company to implement. These strategies involve the way products and information are transferred through the entire supply chain. Sheu [67] finds that Taiwanese firms place a high priority on management control and core competitiveness, and less priority on the firm’s response to its external environment.

10. Critique and Prospects

In earlier sections of this tutorial, the references that we cited have been discussed under one or more categories. Although the classification of a given article may not be clear cut, an overall assessment of the literature can be seen in Tables 1–8. Here, from those same tables, we will note some opportunities for further research. It should be kept in mind, however, that a particular cell may be empty for technical reasons. That is, perhaps one could formulate a more complicated model containing additional global factors; solution of that model may be inhibited by the absence of appropriate bounds or a good decomposition scheme.

Table 1’s matrix, of primary topic and region of focus, is necessarily incomplete. That table simply summarizes those articles that we wished to cite in this tutorial. As just one example, there are clearly many published applications of transportation (such as vehicle routing) in Europe, North America, and elsewhere. Table 1, and our entire tutorial, emphasizes transportation when the materials moved are part of an international supply chain. Similar remarks pertain to most columns in Table 1.

Table 2 did not require as much selective judgment on our part. References such as Vidal and Goetschalckx [73] (1997) and Schmidt and Wilhelm [66] (2000) obviously deal with global supply chains. On the other hand, Boone et al. [10] (1996) and Pontrandolfo and Okogbaa [59] (1999) pertain to international operations and global manufacturing; they have what we feel is a high degree of overlap with our topic. We know of other review papers that overlap to a lesser degree, but with further study of a subset of their subject matter, we could find a stronger correspondence with our research.

One new example of the latter is Melo et al. [51] (2009), which reviews location models in a supply chain context. Some of these will, in our terminology, be global supply chains. Other review papers may contain similar examples of partial overlap, and these could be worth pursuing.

From Table 3 we see that many factors are considered in location models, making it hard to discern any particular trend. As mentioned in §3, all models in this subset assume deterministic conditions, but this does not imply that stochastic programming cannot be utilized for this problem; rather, from our observations, incorporating the variable nature of exchange rates that are typical in global supply chains may only complicate this strategic model.

Sourcing from international suppliers would suggest that characteristics of a procurement model should include standard global factors, such as exchange rates and tariffs; however, the opposite appears true from the results in Table 4. Only Gutierrez and Kouvelis [31] (1995) and Gonzalez Velarde and Laguna [26] (2004) include a combination of exchange rates and duties in their models, whereas Munson and Rosenblatt [55] (1997) and Balaji and Viswanadham [4] (2008) consider LCRs and tax planning, respectively. From these articles we see that there are a number of approaches to determine an optimal procurement strategy, depending on the emphasis a firm places on international factors.

Table 5 shows that transportation models can be applied of course to general international settings (e.g., Chang [17] 2008) or to specific industries and regions. Examples of the latter
include a shortest-path model for NAFTA supply chains (Bookbinder and Fox [9] 1998), an evaluation of the benefits of using a DMCF for air transport (Warsing et al. [76] 2001), and container management in the chemical industry (Erera et al. [23] 2005). Regardless of the application, these models either seek to minimize cost or travel time, or both.

Perhaps the topic that most epitomizes global supply chains is production switching, transfer pricing policies, and postponement. In Table 6, we see that every analytical model features exchange rates. About one-half of the models in that table consider duties and tariffs, and one-half consider transfer prices. One notes from the table, however, that there is not much overlap between these “halves.” Only Vidal and Goetschalckx [74] (2001) and Villegas and Ouenniche [75] (2008) treat both transfer prices and duties and tariffs. In the latter reference, tariffs were implicitly included in some cost parameters. A generalization of that idea may permit expansion to the other global factors of the models in Table 6.

We offer an additional comment on production switching. Suppose a product’s manufacture is moved from Country A to Country B, with no change in the supplier of raw materials. That vendor, in Country A, had been considered domestic but is now international. Many cases of production switching will thus automatically involve duties and tariffs.

Models for network design (Table 7) are potentially the most complicated. The nodal locations are to be chosen, and decision taken on the activities to be carried out at each node. We observe in that table the inclusion of only one, or even zero, global factors for most of the models. Perhaps such factors are not needed for a regional model whose transactions are within a free trade zone. But we note that only Wilhelm et al. [77] (2005) and Goh et al. [25] (2007) incorporate all three global factors. Naturally, the complications of an extra subscript or two, and the presence of additional constraints, may seriously impact the solution’s computation time and its deviation from optimality.

Table 8 summarizes a number of empirical studies. These are in contrast to the normative models that are much more prevalent at an INFORMS conference and in its publications. But the papers in that table belong in this tutorial for the following reasons.

Whereas a normative model can show what ought to be done to improve a global supply chain, a good empirical study can present the current state of affairs. This empirical information can serve a benchmarking function, for that supply chain and its logistics activities, perhaps pointing the way toward a normative model. The articles in Table 8 are thus of overall interest. Additional research may be required, however, to uncover a topic there for further study.

11. Summary

In this tutorial, we have tried to balance several issues. We concentrated on the literature of the past 15 years, the period during which the supply chain concept has emerged and flourished. Even so, various selections needed to be made from our bibliography. Of those interesting references, we were able to discuss only a subset. Those articles are categorized in various ways in Tables 2–8.

No model can be all things to all people. An excellent treatment of a regional supply chain, i.e., one that happens to involve only a single continent, could be more relevant to a proposed new application than a model that attempts a “whole-world” focus. Such a geographical distinction is one of the six dividing factors that we see in the literature. And neither that factor, nor any of the others, may be pertinent in judging the value of a model or application. More is only sometimes better.

Among the excellent regional logistics models are Sheu [67] (2004), Groothedde et al. [29] (2005), and Wilhelm et al. [77] (2005). References such as Kouvelis et al. [41] (2004) and Villegas and Ouenniche [75] (2008) are closer to global in scope. The latter citations needed that focus because of the particular application or problem setting.

Another dividing factor is the use of a deterministic model (Vidal and Goetschalckx [74] 2001, Chang [17] 2008) versus one that is stochastic (Wu and Lin [78] 2005, Goh et al. [25] 2007). The respective titles indicate the model features treated in each case. In those articles,
<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Region</th>
<th>Objective</th>
<th>Time period</th>
<th>Number of products</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bookbinder and Fox [9]</td>
<td>1997</td>
<td>NAFTA</td>
<td>Min cost/ Min travel time</td>
<td>N/A</td>
<td>N/A</td>
<td>Selection of routes for intermodal networks</td>
</tr>
<tr>
<td>McCray and Gonzalez [48]</td>
<td>2008</td>
<td>N. America</td>
<td>Min container processing time</td>
<td>N/A</td>
<td>N/A</td>
<td>Examines the feasibility of using Canadian or Mexican terminals to mitigate congestion at U.S. West Coast</td>
</tr>
<tr>
<td>Nair et al. [57]</td>
<td>2008</td>
<td>Europe</td>
<td>Min cost/ Min travel time</td>
<td>N/A</td>
<td>N/A</td>
<td>Investigates potential for new north–south rail corridor in Europe (REORIENT) and the degree to which these routes are competitive</td>
</tr>
<tr>
<td>Kuo et al. [42]</td>
<td>2008</td>
<td>Europe</td>
<td>Min processing time</td>
<td>N/A</td>
<td>N/A</td>
<td>Proposes three strategies for collaborative decision making to streamline transport along REORIENT corridor</td>
</tr>
<tr>
<td>Janic [36]</td>
<td>2008</td>
<td>Europe</td>
<td>Min cost</td>
<td>N/A</td>
<td>M</td>
<td>Compares performance of using LIFTS versus conventional intermodal freight trains or road</td>
</tr>
<tr>
<td>Warsing et al. [76]</td>
<td>2001</td>
<td></td>
<td>Min cost</td>
<td>M</td>
<td>M</td>
<td>Benefits of using a DMCF versus a traditional passenger-based airport</td>
</tr>
<tr>
<td>Tyan et al. [71]</td>
<td>2003</td>
<td>Asia (Taiwan)</td>
<td>Min cost</td>
<td>M</td>
<td>S</td>
<td>Examines consolidation policies for a 3PL</td>
</tr>
<tr>
<td>Huang and Chi [34]</td>
<td>2007</td>
<td>Europe</td>
<td>Min cost</td>
<td>S</td>
<td>M</td>
<td>Develops a Lagrangian-based heuristic algorithm for an air freight forwarder to determine optimal consolidation policies</td>
</tr>
<tr>
<td>Chang [17]</td>
<td>2008</td>
<td>Europe</td>
<td>Min cost/ Min travel time</td>
<td>M</td>
<td>M</td>
<td>Problem is decomposed into two minimization problems using Lagrangian relaxation</td>
</tr>
<tr>
<td>Neiberger [58]</td>
<td>2008</td>
<td>Europe</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Studies the effect of supply chain configuration on the air freight sector based on interviews with 60 companies</td>
</tr>
<tr>
<td>Erera et al. [23]</td>
<td>2005</td>
<td></td>
<td>Min cost</td>
<td>M</td>
<td>S</td>
<td>Determines optimal policy for container repositioning</td>
</tr>
<tr>
<td>Groothedde et al. [29]</td>
<td>2005</td>
<td>Europe (Netherlands)</td>
<td>Min cost</td>
<td>N/A</td>
<td>N/A</td>
<td>Designs a collaborative intermodal hub network</td>
</tr>
</tbody>
</table>

**Notes:** All models in this subset assume deterministic conditions. S, single; M, multi.

*Paper has been applied to industry/used industry data.*
Table 6. Models for production switching, transfer pricing policies, and postponement.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Model type</th>
<th>Objective</th>
<th>Time period</th>
<th>Number of products</th>
<th>Transfer prices</th>
<th>Exchange rates</th>
<th>Duties and tariffs</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dasu and Li [22]</td>
<td>1997</td>
<td>St/D</td>
<td>Min cost</td>
<td>M</td>
<td>S</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>Determines by how much and when to alter production quantities for a Latin American MNC</td>
</tr>
<tr>
<td>Mohamed [53]</td>
<td>1998</td>
<td>St</td>
<td>Min cost</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>Integrated production and distribution model under varying exchange rate and inflation rates</td>
</tr>
<tr>
<td>Li et al. [43]</td>
<td>2001</td>
<td>St</td>
<td>Min cost</td>
<td>M</td>
<td>S</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Uncertainties in demand, exchange rates, and processing times</td>
</tr>
<tr>
<td>Kazaz et al. [38]</td>
<td>2005</td>
<td>St/D</td>
<td>Max profit</td>
<td>S/M</td>
<td>S</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>Two-stage model that offers the flexibility of using production and allocation hedges</td>
</tr>
<tr>
<td>Wu and Lin [78]</td>
<td>2005</td>
<td>St</td>
<td>Max profit</td>
<td>M</td>
<td>S</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Real options analysis; continuous-time model</td>
</tr>
<tr>
<td>Kouvelis and Gutierrez [40]</td>
<td>1997</td>
<td>St</td>
<td>Min cost</td>
<td>S</td>
<td>S</td>
<td>✓</td>
<td></td>
<td></td>
<td>“Style goods” sold in two international markets with nonoverlapping selling seasons</td>
</tr>
<tr>
<td>Vidal and Goetschalckx [74]</td>
<td>2001</td>
<td>D</td>
<td>Max profit</td>
<td>M</td>
<td>S</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>Transfer prices and allocation of transport costs are explicit decisions</td>
</tr>
<tr>
<td>Miller and de Matta [52]</td>
<td>2008</td>
<td>D</td>
<td>Max profit</td>
<td>S</td>
<td>M</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Max profits on a global basis; both strategic and tactical levels</td>
</tr>
<tr>
<td>Villegas and Ouenniche [75]</td>
<td>2008</td>
<td>D</td>
<td>Max profit</td>
<td>S</td>
<td>M</td>
<td>✓</td>
<td>✓</td>
<td>*</td>
<td>Determines how decisions on trade quantities affect after-tax repatriated earnings</td>
</tr>
<tr>
<td>Hadjinicola and Kumar [32]</td>
<td>2002</td>
<td>D</td>
<td>Max profit</td>
<td>S</td>
<td>M</td>
<td>✓</td>
<td></td>
<td></td>
<td>Examines eight manufacturing-marketing options for a firm with plants in two countries</td>
</tr>
<tr>
<td>Yang and Burns [79]</td>
<td>2003</td>
<td>D</td>
<td>Max profit</td>
<td>S</td>
<td>M</td>
<td>✓</td>
<td></td>
<td></td>
<td>Discussion of current trends in practice and literature</td>
</tr>
<tr>
<td>Jin [37]</td>
<td>2004</td>
<td>D</td>
<td>Max profit</td>
<td>S</td>
<td>M</td>
<td>✓</td>
<td></td>
<td></td>
<td>Finds based on a review of U.S. apparel manufacturing firms</td>
</tr>
<tr>
<td>Yang et al. [80]</td>
<td>2004</td>
<td>D</td>
<td>Max profit</td>
<td>S</td>
<td>M</td>
<td>✓</td>
<td></td>
<td></td>
<td>Literature review</td>
</tr>
<tr>
<td>Prasad et al. [61]</td>
<td>2005</td>
<td>D</td>
<td>Max profit</td>
<td>S</td>
<td>M</td>
<td>✓</td>
<td></td>
<td></td>
<td>Finds based on structured interviews with 30 companies</td>
</tr>
</tbody>
</table>

Notes. D, deterministic; St, stochastic; S, single; M, multi.

aLatin American region.
bNorth American region.

*Implicitly considered.
### Table 7. Overall network design models.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Region</th>
<th>Model type</th>
<th>Objective</th>
<th>Time period</th>
<th>Number of products</th>
<th>Transfer prices</th>
<th>Exchange rates</th>
<th>Duties and tariffs</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arntzen et al. [1]</td>
<td>1995</td>
<td>D</td>
<td>Min cost</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>Considers global BOM, offset trade, and LCRs; can handle multiple measures of time</td>
</tr>
<tr>
<td>Camm et al. [12]</td>
<td>1997</td>
<td>D</td>
<td>Min cost</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Uses GIS to solve distribution location and product sourcing models</td>
</tr>
<tr>
<td>Dasu and de la Torre [21]</td>
<td>1997</td>
<td>Latin America</td>
<td>D</td>
<td>Max Profit</td>
<td>S</td>
<td>S</td>
<td>✓</td>
<td></td>
<td></td>
<td>Considers the coordinating activities and allocation of gains for an MNC’s subsidiaries</td>
</tr>
<tr>
<td>Tsiakis et al. [70]</td>
<td>2001</td>
<td>Europe</td>
<td>D</td>
<td>Min cost</td>
<td>S</td>
<td>M</td>
<td></td>
<td></td>
<td>*</td>
<td>Economies of scale for transportation costs; decides locations for facilities at two echelons (in a four-echelon system)</td>
</tr>
<tr>
<td>Sheu [67]</td>
<td>2004</td>
<td>Asia (Taiwan)</td>
<td>Fuzzy MADM/ Fuzzy AHP</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>*</td>
<td></td>
<td></td>
<td>Determines best global logistics strategy for an integrated circuit manufacturer using fuzzy AHP and fuzzy MADM</td>
</tr>
<tr>
<td>Contesse et al. [19]</td>
<td>2005</td>
<td>S. America (Chile)</td>
<td>D</td>
<td>Min cost</td>
<td>M</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td>MIP model for a natural gas supply chain</td>
</tr>
<tr>
<td>Nagurney and Matsypura [56]</td>
<td>2005</td>
<td>St</td>
<td>Max profit/ Min risk</td>
<td>S</td>
<td>S</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Manufacturers, distributors, and retailers; both supply-side and demand-side risks</td>
</tr>
<tr>
<td>Santoso et al. [65]</td>
<td>2005</td>
<td>U.S. and Latin America</td>
<td>St</td>
<td>Min cost</td>
<td>S</td>
<td>M</td>
<td></td>
<td></td>
<td>*</td>
<td>Large-scale stochastic programming; sample-average-approximation scheme with accelerated Benders decomposition</td>
</tr>
<tr>
<td>Wilhelm et al. [77]</td>
<td>2005</td>
<td>NAFTA</td>
<td>D</td>
<td>Max profit</td>
<td>M</td>
<td>M</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Includes modal decisions, BOM restrictions, and income taxes</td>
</tr>
<tr>
<td>Goh et al. [25]</td>
<td>2007</td>
<td>St</td>
<td>Max profit</td>
<td>M</td>
<td>S</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Risks in supply, demand, exchange rates, and disruption</td>
</tr>
</tbody>
</table>

**Notes.** D, deterministic; St, stochastic. S, single; M, multi.

*a Paper has been applied to industry/used industry data.

*Implicitly considered.
Table 8. Other papers (empirical studies).

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Region</th>
<th>Data type</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynch et al. [45]</td>
<td>1994</td>
<td>N. America (Canada)</td>
<td>Primary</td>
<td>Forecasts the future of logistics in Canada using a Delphi study</td>
</tr>
<tr>
<td>Bolisani and Scarso [8]</td>
<td>1996</td>
<td>Europe (Italy)</td>
<td>Secondary + Interviews</td>
<td>Determines why, where, and how Italian clothing firms internationalized</td>
</tr>
<tr>
<td>Das and Handfield [20]</td>
<td>1997</td>
<td>N. America</td>
<td>Primary</td>
<td>Uses a survey to compare JIT and global sourcing</td>
</tr>
<tr>
<td>Morash and Clinton [54]</td>
<td>1997</td>
<td>Primary</td>
<td></td>
<td>Uses a survey to compare transportation in Korea, Japan, Australia, and U.S.</td>
</tr>
<tr>
<td>MacCarthy and Atthirawong [46]</td>
<td>2003</td>
<td>Primary</td>
<td></td>
<td>Determines factors influencing international facility location decisions using a Delphi study</td>
</tr>
<tr>
<td>McCalla et al. [47]</td>
<td>2004</td>
<td>Primary</td>
<td></td>
<td>Comparison of containerization in E. Asia, N. America, and NW Europe</td>
</tr>
<tr>
<td>Carbone and Stone [16]</td>
<td>2005</td>
<td>Europe</td>
<td>Secondary + Interviews</td>
<td>Examines growth of 3PLs in Europe</td>
</tr>
<tr>
<td>Steenhuis and De Bruijn [68]</td>
<td>2004</td>
<td>N/A</td>
<td></td>
<td>Uses GDP to assess feasibility of locating a facility in a certain country; based on the aircraft industry</td>
</tr>
<tr>
<td>Robertson et al. [62]</td>
<td>2002</td>
<td>Oceania</td>
<td>Primary</td>
<td>Describes how the development of a sales and operations plan and master production schedule for a particular firm has improved its production and social processes</td>
</tr>
<tr>
<td>Meijboom and Voordijk [49]</td>
<td>2003</td>
<td>Europe (Netherlands)</td>
<td>Primary</td>
<td>Determines why Dutch companies remain regional in spite of widespread globalization</td>
</tr>
<tr>
<td>Liu and Young [44]</td>
<td>2004</td>
<td>N/A</td>
<td></td>
<td>Coordination of global manufacturing with emphasis on information and knowledge</td>
</tr>
<tr>
<td>Buxey [11]</td>
<td>2005</td>
<td>Australia</td>
<td>Primary</td>
<td>Documents how Australian TCF industry has responded to globalization</td>
</tr>
<tr>
<td>Stratton and Warburton [69]</td>
<td>2006</td>
<td>Primary</td>
<td></td>
<td>Evaluates how outsourcing affects company performance</td>
</tr>
<tr>
<td>Rudberg and West [64]</td>
<td>2008</td>
<td>Europe (Sweden)</td>
<td>Secondary</td>
<td>Concept for coordinating manufacturing networks</td>
</tr>
</tbody>
</table>

*Paper has been applied to industry/used industry data.
the choice of model type therefore seems logical. Further research would be desirable to elaborate the trade-offs in such a choice. In the case of international supply chains, a greater number of factors may impact the selection of model type here than in some other operations research applications.

Manufacturing is included in some models (e.g., Arntzen et al. [1] 1995, Wilhelm et al. [77] 2005) but not in others. Even when a supply chain model involves manufacturing, that may not be an essential component; Wilhelm et al. [77] (2005) is one exception.

Similar remarks pertain to location decisions. When the nodes for production and distribution are already fixed, as they are in Gonzalez Velarde and Laguna [26] (2004) and in Balaji and Viswanadham [4] (2008), the model will often emphasize decisions on which products to produce in a particular plant, and the choice of DC through which they should flow to satisfy demand of specific customers. On the other hand, references such as Canel and Das [13] (2002), Kouvelis et al. [41] (2004), and Hamad and Gualda [33] (2008) are essentially location models for global logistics and manufacturing.

Questions of transportation are an obvious feature of international supply chains; raw materials and end items need to get from here to there. What is not so obvious is that the model’s time scale can influence whether decisions on mode can be included in such a model. Let us give several examples.

The location of long-term facilities, as a strategic choice, may be based on an annual model (e.g., Canel and Khumawala [15] 2001). This might involve a weighted average over transport modes, effectively concentrating on decisions other than selection of mode of transportation. Even a “domestic” model, where given arcs may be traversed by rail or truck, requires a weekly time scale, say, for the model to aid in this choice. (Those are the relevant modes and time scales in the NAFTA location model of Robinson and Bookbinder [63] (2007).) The possible modes are more likely air and water in a global model. But the time scale must still be fine enough to account for differences in transportation lead times, and to incorporate pipeline inventories.

Finally, we distinguish between the “business features” of a problem or case study, and the “modeling features” that the analysis must therefore comprise. Issues such as tariffs, duties, and quotas (e.g., Gutierrez and Kouvelis [31] 1995, Bhutta et al. [6] 2003, Goh et al. [25] 2007) are business features that can be difficult to model. Models of supplier selection in an international setting, such as in Munson and Rosenblatt [55] (1997) and Gonzalez Velarde and Laguna [26] (2004), are challenging for business reasons, but perhaps not for mathematical ones. Models that incorporate multiple stages of a global supply chain will pose mathematical challenges. References such as Kazaz et al. [38] (2005) on implementing production and allocation hedging when faced with exchange rate uncertainty, and Santoso et al. [65] (2005) on designing a supply chain network in a stochastic environment, have thus stressed the solution methodologies involved.

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