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Configuring Multi-Stage Global Supply Chains with Uncertain Demand

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1. Introduction

Global outsourcing has emerged as one of the major approaches for many industries to gain competitive edge. The movement of the domestic supply chains towards globalization involves the company's worldwide interests and necessitates a unified way of managing and coordinating activities all across the globe.

As the result of globalization, research in global supply chains is receiving more and more attention and many studies have been conducted to tackle various features associated with global networks. In this chapter we focus on the configuration of the global supply chains facing uncertain demand. We specifically intend to coordinate the supplier selection with global production-distribution decisions such as the determination of the capacity of each manufacturing facility and the material flow between different facilities.

Based on the literature review an issue that has not received enough attention in this research area is the uncertainty factor. Schmidt & Wilhelm (2000) and Santoso *et al.* (2004) mention that few studies have addressed the uncertainties associated with global networks. Uncertainties are integral parts of global companies and failing to incorporate these factors in any model trying to tackle global supply chain problems might result in great financial losses or even failure of the business.

The policy for selecting suppliers is one of the most crucial decisions which affects both the quality and cost of the products, especially in IT and manufacturing industries. There are a vast number of emerging small and medium-sized enterprises especially in Asia which are selected everyday to serve as major outsourcing targets due to their lower labor and material costs. Only a few researches in the global context focus on the capacitated supplier selection issues under demand uncertainty and combining the supplier selection issue with global production-distribution decisions is an important feature of our model, Qi (2007).

In global supply chain management it is very important to consider the overall costs of the network. While labor and production costs may be significantly lower across the border companies must also consider other factors such as exchange and tariff rates, costs of space, governmental considerations and global trade issues. The proposed model considers the

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exchange and tariff rates which are one of the deciding factors in selecting the most appropriate locations across the globe for investments or choosing the right outsourcing partners.

A two-stage stochastic programming method is employed to solve the stochastic problem and the scenario-based approach is used to model the uncertain variables. A mixed-integer linear program is developed to formulate the whole problem and it is finally applied to do some sensitivity analyses in order to obtain managerial insights.

The rest of the chapter is organized as follows: Section 2 presents the literature review. Section 3 introduces the two-stage stochastic programming method. Examples and numerical results are discussed in Section 4 and the last section concludes our work.

2. Literature review

The reviewed literature has been divided into three main categories: supplier selection under demand uncertainty, stochastic supply chain design and global supply chain design.

2.1 Supplier selection under demand uncertainty

There is a growing interest in research on the supplier selection under demand uncertainty. Kim *et al.* (2002) investigated how to configure a supply network with uncertain consumer demands for multiple products. They then analyzed the Lagrangian relaxation and optimality conditions of the problem and finally developed an iterative algorithm to solve the model.

Alonso-Ayuso (2003) presented a two-stage stochastic 0-1 model for supply chain management under uncertainty in order to determine the production topology, plant sizing, product selection, product allocation among the plants and the vendor selection for raw materials.

Shu *et al.* (2005) studied the stochastic transportation-inventory network design problem consisting of one supplier and multiple retailers facing uncertain demand. The problem involves the allocation of retailers to distribution centres and is formulated as a set-covering integer programming model.

Qi (2007) studied an integrated decision making model that takes into account the price-sensitive demand and multiple capacitated suppliers. Zhang & Ma (2007) considered both demand uncertainty and quantity discount in acquisition policies for a supply network involving one manufacturer and multiple suppliers, both subject to capacity limitations.

2.2 Stochastic supply chain design

There exist several stochastic factors in today's supply chains. Most of the researches that address the uncertainties use two distinct approaches: probabilistic approach or scenario planning approach. The choice of the most appropriate strategy is very dependant on the context and the extent of available data, Zimmermann (2000). Two-stage stochastic programming method is an approach which is widely used in the literature, Cheung *et al* (1996), Mirhassani *et al* (2000), Tsiakis *et al* (2001), Gupta & Maranas (2000) and (2003), Chen *et al* (2004), Santoso *et al* (2004) and Guillén *et al* (2005).

Gupta & Maranas (2000) and (2003), propose a two-stage stochastic programming approach for incorporating demand uncertainty in multi-site midterm supply chain planning

problems, adopting the midterm planning model of McDonald & Karimi (1997) as the reference model. The inner optimization problem is solved by obtaining its closed-form solution using linear programming (LP) duality. The extension of this work is to account for a general probability distribution and to incorporate the uncertainty in revenue, transportation and penalty costs.

Tsiakis *et al.* (2001) consider the design of a multi-product, multi-echelon supply chain and determine the capacity and location decisions. They consider economies of scale in transportation costs and use the two-stage stochastic programming method assuming only three possible scenarios to model the uncertainty in demand.

Fewer researches address multiple objectives in their model. Typical objectives besides cost minimization and profit maximization are fair profit distribution, safe inventory levels, and maximum customer service level, Chen *et al* (2004) and Guillén *et al* (2005).

2.3 Global supply chain design

Recently there has been significant work done in domestic supply chain design and facility location problems under both deterministic and stochastic conditions. Fewer researches have focused on the supply chains operating under international conditions such as exchange and tariff rates, governmental regulations etc.

Hodder & Jucker (1985) tackle the international plant location problem under price and exchange rate uncertainty for a mean-variance decision maker. They redefine the profit maximizing objective function using the decision maker's risk aversion coefficient and provide an analytical framework to solve the mixed-integer quadratic programming problem. The objective is maximizing the profit under deterministic conditions. The paper does not consider the different stages in global supply chains.

Transfer price is the price that a selling department, division, or subsidiary of a company charges for a product or service supplied to a buying department, division, or subsidiary of the same firm, Abdallah (1989). Goetschalckx *et al* (2002) demonstrate the savings potential generated by the integration of the design of strategic global supply chain networks, with the determination of tactical production–distribution allocations and transfer prices. They mention that transfer pricing is one of the most important issues today's multinational companies face.

Mohamed (1999) proposes a model that considers production and logistics decisions for multinational companies. The decisions made are sensitive to inflation and exchange rates, capacity levels and the efficiency of the plants. It does not consider the stochasticity in demand or in other factors involved in multinational environments and considers only the minimization of costs as an objective. Bhutta *et al.* (2003) extend the previously published models on multinational facility location problems and incorporate production, distribution and investment decisions. The model does not consider the uncertainties present in multinational environments.

A comprehensive literature review on strategic, tactical and operational aspects of international logistics networks is presented by Schmidt & Wilhelm (2000). They discuss the relevant modeling issues for each of the aspects and mention that few studies have addressed the uncertainties associated with tactical aspects of the global logistics networks. They mention that there is the need for an approach that unifies all the three planning levels coupled with efficient solution approaches that can solve realistic instances of the models.

Meixell *et al.* (2005) review the decision support models for the design of global supply chains. They mention that although most models tackle a difficult feature associated with globalization, few models address the practical global supply chain design. As a future research they recommend considering multi-tier supply chains with internal production sites and external suppliers, more performance criteria and a wider variety of industries.

A group of global supply chain models address the relevant issues and considerations for the business environment under NAFTA, Bookbinder & Fox (1998), Wilhelm *et al.* (2005) and Robinson & Bookbinder (2007). Bookbinder & Fox (1998) obtain the optimal routings for intermodal containerized transport from Canada to Mexico with the associated transportation costs for two transportation modes and the respecting lead-times. In another recent work, Robinson & Bookbinder (2007) formulate and solve a mixed-integer programming model to find the optimal supply chain for a real world problem of a Canadian manufacturer of power supplies.

3. Multi-stage global supply chains design with uncertain demand

Consider a global supply network that consists of suppliers, manufacturing facilities, distribution centres and customer (retail) zones. We assume that the decisions on the selection of manufacturing facilities, distribution centres and suppliers and also delivery to customer zones are all controlled by a centralized manufacturer. The objective of the problem is to configure the whole supply network so that the expected total cost is minimized considering the target demand satisfaction level.

Stochastic customer demand can be met from any distribution centre via different transportation modes. Depending on the lost sale and overstocking costs and penalties, type and importance of the products and customers or other policies or considerations the company might pursue, different target service levels or transportation modes with longer or shorter lead-times might be selected.

Our model allows expansion over the maximum available capacity at each facility. This feature of the model captures the tradeoffs between capacity expansion and moving production to the facilities with higher available capacity.

We assume that there is not enough available information about the probability distributions of the demand but based on historical data several scenarios with known probabilities can be generated which help model the uncertainties using the scenario-based approach.

The two-stage stochastic programming method is used to formulate the stochastic problem. In the proposed model the supplier selection, production and capacity expansion decisions are first-stage decisions which are made prior to the demand realization, whereas distribution decisions to the customer zones are second-stage variables which are postponed until the uncertain variable is realized.

The network studied in this work consists of h domestic suppliers, g international suppliers, m domestic manufacturing facilities, n international manufacturing facilities, d distribution centres and c customer zones. As the result there will be $(h+g+m+n+d+c)$ nodes in the network. We use the notation given in Appendix A to develop our model. We will first discuss the terms in the objective function and then the model constraints.

3.1 Objective function

The overall objective of the problem is the minimization of costs and maximization of the customer expected average service level. As previously mentioned the focus should be on minimizing the *overall* costs since moving directly to the locations with the lower costs is not always the best case and several other tradeoffs should be considered in order to make the most appropriate decisions.

The solution of the multi-objective problem consists of a set of Pareto optimal global network configurations which is obtained by the ϵ -constraint method, Haimes *et al* (1971). Based on this method the minimization of the total cost is kept as the main objective function and maximization of the expected average service level is added as a constraint to the model, bounded by some feasible ϵ . Different levels of ϵ generate the entire Pareto optimal set, Guillén *et al* (2005). We seek to find the maximum allowable ϵ until the decision maker is satisfied with the level of service. In the scenario-based approach the uncertainty is captured in terms of several discrete realization scenarios of the stochastic variables. The objective is to find the best solution under all scenarios which minimizes the total cost of the first-stage variables plus the expected cost of the second-stage variables with respect to the minimum accepted service level.

We consider three demand realizations scenarios: high, medium and low, to capture optimistic, likely and pessimistic possible outcomes of the demand for each customer zone. This leads to $N_{js} = 3^c$ joint demand scenarios with their corresponding probabilities, where c is the total number of customer zones. We assume the probability of the occurrence of each individual scenario s for each customer is known, thus the probability of the occurrence of the joint scenarios js , can be easily calculated. It should be noted that the decision variables with superscript s correspond to the second-stage stochastic variables and the joint probabilities will satisfy:

$$\sum_{js=1}^{N_{js}} \xi_{js} = 1. \quad (1)$$

In the following sections we formulate each of the cost components that are involved in the supply network and the related constraints.

3.1.1 Raw material cost

The total purchasing costs of raw material is determined by the supplier selection decision and then the raw material allocation among the suppliers:

$$RC = \sum_{i=1}^I \sum_{j=1}^h \sum_{k=h+g+1}^{h+g+m} \sum_t c_{ijk} x_{ijkt} + \sum_{i=1}^I \sum_{j=h+1}^{h+g} \sum_{k=h+g+m+1}^{h+g+m+n} \sum_t c_{ijk} x_{ijkt}. \quad (2)$$

The first term is the total raw material cost for the domestic plants and the second term corresponds to the same cost for the international plants. Without loss of generality we assume that the plants only procure raw materials from the local suppliers within the same country.

3.1.2 Production cost

Economies of scale are present in production costs. For each of the manufacturing facilities the production amount is divided into NR_j sub-ranges each corresponding to a lower unit production cost. The total production cost is modeld as a piecewise linear function of the production amount as shown in Figure 1. In order to calculate the total production costs at domestic plants we introduce the binary variable V_{jpt} , which defines the range the production amount belongs to:

$$V_{jpt} = \begin{cases} 1, & \text{if } Q_{jt} \in [\bar{Q}_{p-1}, \bar{Q}_p] \\ 0, & \text{otherwise.} \end{cases}$$

In order to ensure that the production amount belongs to only one sub-range we use the following constraint:

$$\sum_{p=1}^{NR_j} V_{jpt} \leq 1 \quad \forall t, j = h + g + 1, \dots, h + g + m. \quad (3)$$

The production amount is then modeld as:

$$\bar{Q}_{p-1} V_{jpt} \leq Q_{jpt} \leq \bar{Q}_p V_{jpt} \quad \forall t, p = 1, \dots, NR_j, j = h + g + 1, \dots, h + g + m, \quad (4)$$

$$Q_{jt} = \sum_{p=1}^{NR_j} Q_{jpt} \quad \forall t, j = h + g + 1, \dots, h + g + m. \quad (5)$$

Finally the total production cost at the domestic plants is calculated as:

$$PC = \sum_{j=h+g+1}^{h+g+m} \sum_t \sum_{p=1}^{NR_j} \left[\overline{UPC}_{p-1} V_{jpt} + (Q_{jpt} - \bar{Q}_{p-1} V_{jpt}) \frac{\overline{UPC}_p - \overline{UPC}_{p-1}}{\bar{Q}_p - \bar{Q}_{p-1}} \right]. \quad (6)$$

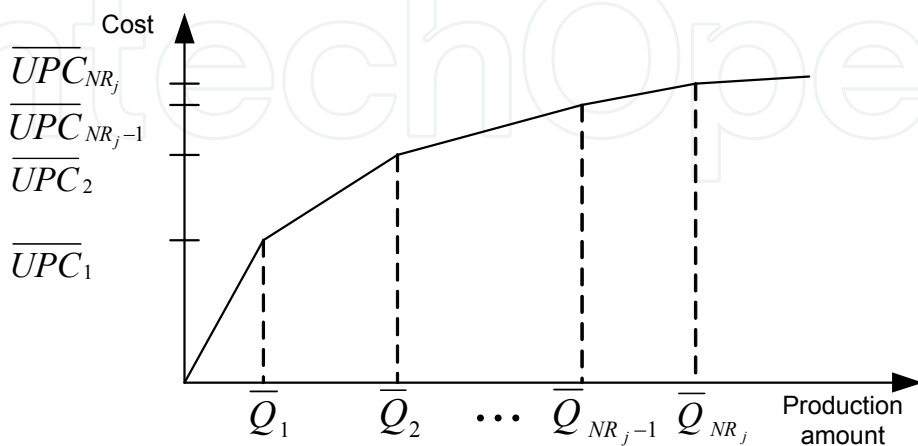


Figure 1. Economies of scale in production cost

We take the same procedure to calculate the total production costs at international plants considering the exchange rate factor:

$$PCI = \sum_{j=h+g+m+1}^{h+g+m+n} \sum_t \frac{1}{E_{jt}} \sum_{p=1}^{NR_j} \left[\overline{UPC}_{p-1} V_{jpt} + (Q_{jpt} - \overline{Q}_{p-1} V_{jpt}) \frac{\overline{UPC}_p - \overline{UPC}_{p-1}}{\overline{Q}_p - \overline{Q}_{p-1}} \right]. \quad (7)$$

3.1.3 Transportation cost

The transportation cost incurred at the plants and distribution centres is assumed to be proportional to the shipment amount with a constant unit transportation cost as well as the pipeline inventory cost, Robinson & Bookbinder (2007). The corresponding term in the objective function is of the following form:

$$TC = \sum_{j=h+g+1}^{h+g+m} \sum_{k=h+g+m+n+1}^{h+g+m+n+d} \sum_r \sum_t (UTC_{jkr} + PI \times LT_{jkr}) Q_{jkrt}, \quad (8)$$

$$TCI = \sum_{j=h+g+m+1}^{h+g+m+n} \sum_{k=h+g+m+n+1}^{h+g+m+n+d} \sum_r \sum_t \frac{1}{E_{jt}} (UTC_{jkr} + PI \times LT_{jkr}) Q_{jkrt}, \quad (9)$$

$$TCD = \sum_{j=h+g+m+n+1}^{h+g+m+n+d} \sum_{k=h+g+m+n+d+1}^{h+g+m+n+d+c} \sum_r \sum_t (UTC_{jkr} + PI \times LT_{jkr}) Q_{jkrt}. \quad (10)$$

The raw material transportation cost is not considered in the model with the assumption that either it is already included the transportation costs or the supplier is responsible for delivering the raw materials to the manufacturing sites.

3.1.4 Capacity expansion cost

The model allows the expansion of capacity over the maximum amount of available resources but there is a limit for such expansion. Based on the chase strategy for aggregate planning we assume the capacity, such as the workforce, can be adjusted from period to period. Here the model decides between outsourcing the production to the international plants with greater capacity or expanding the existing capacity at the domestic plants. It is assumed that the capacity expansion cost is lower at international locations. The capacity expansion cost at the domestic and international plants is:

$$TCapCj = \sum_{j=h+g+1}^{h+g+m} \sum_t CapC_j \times \max(0, Cap_{jt} - Cap_{max_j}), \quad (11)$$

$$TCapCjI = \sum_{j=h+g+m+1}^{h+g+m+n} \sum_t \frac{1}{E_{jt}} \times CapC_j \times \max(0, Cap_{jt} - Cap_{max_j}). \quad (12)$$

To avoid the computational complexity of the above mentioned nonlinear constraints, we introduce the binary variable y_{jt} which shows if capacity expansion occurs at plant j in period t or not:

$$\begin{aligned}
 y_{jt} \text{Cap max}_j &\leq u_{1jt} \leq y_{jt} M, \quad \forall t, j = h+g+1, \dots, h+g+m \\
 0 \leq u_{2jt} &\leq (1-y_{jt}) \text{Cap max}_j, \quad \forall t, j = h+g+1, \dots, h+g+m \\
 \text{Cap}_{jt} &= u_{1jt} + u_{2jt}, \quad \forall t, j = h+g+1, \dots, h+g+m.
 \end{aligned} \tag{13}$$

And the total capacity expansion costs will be calculated as follows:

$$\begin{aligned}
 \text{TCapC} &= \sum_{j=h+g+1}^{h+g+m} \sum_t \text{CapC}_j \times (u_{1jt} - \text{Cap max}_j \times y_{jt}) \\
 &+ \sum_{j=h+g+m+1}^{h+g+m+n} \sum_t \frac{1}{E_{jt}} \times \text{CapC}_j \times (u_{1jt} - \text{Cap max}_j \times y_{jt}).
 \end{aligned} \tag{14}$$

The above mentioned terms correspond to the capacity expansion costs for the domestic and international plants respectively.

3.1.5 Tariff cost

Countries impose various restrictions on products coming into their markets, sometimes in shape of tariff or import duties which is usually expressed as a percentage of the selling price or the manufacturing cost, Bhutta *et al* (2003). In our model tariff cost occurs whenever the production is outsourced to the international manufacturing facilities and is then shipped to the distribution centres in other countries. The tariff cost is expressed as a percentage of the total manufacturing costs incurred at the international plants. This percentage which expresses the tariff rates varies between each two different countries:

$$\text{TarC} = \sum_{j=h+g+m+1}^{h+g+m+n} \text{Tariff}_j \sum_t \frac{1}{E_{jt}} \sum_{p=1}^{NR_j} \left[\overline{UPC}_{p-1} V_{jpt} + (Q_{jpt} - \bar{Q}_{p-1} V_{jpt}) \frac{\overline{UPC}_p - \overline{UPC}_{p-1}}{\bar{Q}_p - \bar{Q}_{p-1}} \right]. \tag{15}$$

3.1.6 Inventory cost

Inventory costs at the manufacturing and distribution facilities are assumed to be proportional to the amount kept in inventory with respect to the unit inventory cost:

$$\text{IC} = \sum_{j=h+g+1}^{h+g+m} \sum_t \text{UIC}_j \times I_{jt} + \sum_{j=h+g+m+1}^{h+g+m+n} \sum_t \frac{1}{E_{jt}} \times \text{UIC}_j \times I_{jt} + \sum_{j=h+g+m+n+1}^{h+g+m+n+d} \sum_t \text{UIC}_j \times I_{jt}. \tag{16}$$

3.1.7 Expected lost sale and overstock cost

The expected lost sale and overstock amounts are second-stage variables and the associated costs under each joint scenario are calculated with respect to their penalties. This gives the decision maker the flexibility to adjust the service level and the probability of meeting the demand for each customer zone individually. The decision variables with superscript s correspond to the second-stage stochastic variables:

$$\sum_{js=1}^{N_{js}} \xi_{js} \sum_{l=h+g+m+n+d+1}^{h+g+m+n+d+c} \sum_t \left[LC \times \text{LostSale}_{l,t,js}^s + OC \times \text{Overstock}_{l,t,js}^s \right]. \tag{17}$$

The objective function of minimizing the overall costs is developed by the summation of all the previously discussed costs.

3.2 Constraints

In this section we explain the problem constraints. The capacity of the manufacturing facilities at both domestic and international locations should be at least equal to the production amount at the facilities. This allows the production amount exceed the maximum available capacity at each facility at the expense of incurring capacity expansion costs:

$$Q_{jt} \leq Cap_{jt} \quad \forall t, j = h + g + 1, \dots, h + g + m + n. \quad (18)$$

We impose the resource constraints for the suppliers to ensure that the amount of resource required for supplier j to produce a certain number of raw materials is within its resource capacity:

$$\sum_{i=1}^I \sum_{k=h+g+1}^{h+g+m} \beta_{ij} x_{ijkt} \leq q_j \quad \forall t, j = 1, \dots, h, \quad (19a)$$

$$\sum_{i=1}^I \sum_{k=h+g+m+1}^{h+g+m+n} \beta_{ij} x_{ijkt} \leq q_j \quad \forall t, j = h + 1, \dots, h + g. \quad (19b)$$

Raw material requirement constraints are to ensure there are sufficient raw materials for the production planning in the period t :

$$\alpha_i Q_{kt} \leq \sum_{j=1}^h x_{ijkt} \quad \forall t, i, k = h + g + 1, \dots, h + g + m, \quad (20a)$$

$$\alpha_i Q_{kt} \leq \sum_{j=h+1}^{h+g} x_{ijkt} \quad \forall t, i, k = h + g + m + 1, \dots, h + g + m + n. \quad (20b)$$

The production level at each manufacturing plant in each period plus the remaining inventory level from the previous period must be equal to the total outgoing flow from each plant to all distribution centres via all transportation modes plus the excess inventory which is carried over to the following periods:

$$Q_{jt} + I_{j,t-1} = \sum_{k=h+g+m+n+1}^{h+g+m+n+d} \sum_r Q_{jkrt} + I_{jt} \quad \forall t, j = h + g + 1, \dots, g + h + m + n. \quad (21)$$

If the initial inventory levels at the manufacturing and distribution facilities are assumed to be zero, the customer demand might be lost for the initial planning periods, depending on the lead-times between different stages of the supply chain. Of course if the decision maker assumes initial inventories at the manufacturing facilities the service level will improve:

$$I_{j,0} = 0 \quad \forall t, j = g + h + 1, \dots, g + h + m + n + d \quad (22)$$

The total amount each distribution centre ships to the customer zones via all transportation modes plus the excess inventory carried over to the following periods should be equal to the sum of the amount received from all the domestic and international facilities by all transportation modes considering the associated lead-times, plus the remaining inventory from the previous period:

$$\sum_{j=h+g+1}^{h+g+m+n} \sum_r Q_{jkr,t-LT_{jk}} + I_{k,t-1} = \sum_{l=h+g+m+n+d+1}^{h+g+m+n+d+c} \sum_r Q_{klrt} + I_{kt} \quad (23)$$

$$\forall t, k = h + g + m + n + 1, \dots, h + g + m + n + d.$$

The decision on expected sales, overstock and lost sale amounts which are second-stage variables is postponed until the realization of the stochastic variable; thus the amount shipped from the distribution centres to each customer zone via all transportation modes results in sales or overstocking based on the target service level under each joint scenario:

$$\sum_{k=h+g+m+n+1}^{h+g+m+n+d} \sum_r Q_{klr,t-LT_{klr}} = Sales_{l,t,js}^s + Overstock_{l,t,js}^s \quad (24)$$

$$\forall t, js, l = h + g + m + n + d + 1, \dots, h + g + m + n + d + c.$$

The stochastic lost sale for each customer and time period is the difference between the stochastic demand and the stochastic sales under each joint scenario:

$$LostSale_{l,t,js}^s = demand_{l,js}^s - Sales_{l,t,js}^s \quad (25)$$

$$\forall t, js, l = h + g + m + n + d + 1, \dots, h + g + m + n + d + c.$$

The stochastic sales to each customer can not exceed the total amount shipped to the customers or each customer stochastic demand. Under each joint scenario and time period if the realized demand is smaller than the shipped amount, the stochastic sales can not exceed the demand and if the realized demand is greater than the shipped amount, the stochastic sales can not exceed the shipped amount:

$$Sales_{l,t,js}^s \leq \min(demand_{l,js}^s, \sum_{k=h+g+m+n+1}^{h+g+m+n+d} \sum_r Q_{klr,t-LT_{klr}}) \quad (26)$$

$$\forall t, js, l = h + g + m + n + d + 1, \dots, h + g + m + n + d + c.$$

Using the ε - constraint method, the objective of maximizing the expected service level has been added to the problem constraints bounded by the minimum accepted expected service level ε . The demand is uncertain and in order to define the production and transportation levels, the expected average service level is used as a measure in order to give the decision maker the ability of setting the company policies in terms of the extent of meeting the demand for each specific customer. The expected average service level is defined as the

expected sales over the expected demand, Chen *et al* (2004) and Guillén *et al* (2005). The expected sale is a second-stage decision variable:

$$ASL = \frac{1}{c \times T} \sum_{l=h+g+m+n+d+1}^{h+g+m+n+d+c} \sum_{js} \frac{\xi_{js} \times Sales_{l,t,js}^s}{\sum_{js} \xi_{js} \times demand_{l,js}^s} \geq \varepsilon \cdot \quad (27)$$

Finally all we present the non-negativity and binary constraints:

$$V_{jpt} \in \{0,1\}, \quad (28)$$

$$y_{jt} \in \{0,1\}, \quad (29)$$

$$\text{all variables} \geq 0. \quad (30)$$

4. Experimental design

4.1 Model assumptions

In order to study the applicability of the proposed model we have considered a hypothetical network setting. The network addresses a Canadian company which has three manufacturing plants in Toronto, Calgary and Montreal and two distribution centres in Vancouver and Toronto. The main customer zones are Toronto, Halifax, Seattle, Chicago and Los Angeles. The company has the option of outsourcing its production to three candidate manufacturing plants in Mexico in Monterrey, Mexico City and Guadalajara and distributing through two candidate distribution centres in the US in Los Angeles and Houston. Of course any country can be selected based on the respecting exchange and tariff rates.

We consider three transportation modes of rail, truck and a combination of the two transportation modes. Again any transportation mode can be adopted in our model based on the cost and lead-time of each mode. We consider a single product without specifying its type as our main goal is to keep our model general so that it can be easily suited to different situations. The tool to adjust the proposed model to different supply chain and product types are the target service level, transportation mode selection with shorter or longer lead-times and the possibility of overstocking or losing the customer order. Our model is one of the few practical models which can be conveniently customized for various real world supply chains.

We have made some assumptions throughout the cases studied in this chapter. First of all we only consider tactical level decisions and the size of the facilities are small enough that can be either used or not at each planning period meaning that there is no long-term contract or ownership of the facilities. There is no restriction on the number of facilities serving each distribution centre or customer zone. Finally border crossing costs are assumed to be included in the transportation costs form international facilities to different destinations

Most of the input data on the transportation costs, transportation modes and the associated lead-times have been derived from Bookbinder & Fox (1998). The suppliers and raw

materials related information and data has been taken from the first example of Kim *et al.* (2002).

It should be noted that in general all the studied cases are hypothetical and based on the input parameters and assumption of zero initial inventory, lost sale and overstock levels. It is assumed in the model that the production, capacity expansion and inventory costs are lower at international locations.

4.2 Numerical example and cases

We assume that the manager of the above mentioned hypothetical company wants to decide on the expansion of its existing facilities or outsourcing to the potential international plants. We consider three general cases and then present our results and observations: 1) in the first base case we assume that the company has the option of outsourcing its production to international manufacturing facilities, 2) in the second case it is assumed that the entire manufacturing is outsourced and thus there is no in-house production and 3) in the third case it is assumed that all the production should be done domestically. All the cases are studied in 12 planning periods which is sufficient in order to maintain feasibility with respect to the transportation lead-times.

4.3 Observations

The problem has been modeled in AMPL and solved by CPLEX optimization software. The comparison of the results of the three cases in terms of the objective function values and different costs is given in Table 1 and Table 2.

Case	Total Cost	% Change in total cost	Maximum possible service level	% Change in service level	95% Maximum Service level	Total Cost	% Decrease in total cost
I. Base case	3892307.95	N/A	90.9%	N/A	86.3%	3591397.94	7.73%
II. Full outsourcing	5193925.01	33.4% increase	65.5%	14.6% decrease	62.2%	4923506.84	5.21%
III. No outsourcing	4161147.32	6.9% increase	90.9%	Same	86.3%	3829202.5	7.98%

Table 1. Comparison of the objective function values

According to the results in Table 1, both cases I and III have the same maximum possible service level while case I has the lowest total costs. Case II incurs the highest total costs and lowest service level. The solution in Table 1 also indicates that the total cost can be reduced as much as 7.98% if the service level is reduced to 95% of the maximum. The solution suggests serving a large portion of the Canadian customers from Canadian distribution centres and also two of the three customer zones in Seattle and Chicago would be served from Vancouver and Toronto respectively. As the result when the company outsources the

whole manufacturing to Mexico, despite the fact that manufacturing costs decrease by 91%, transportation and lost sale costs increase by 65%, 114%. The reason is that in order to serve the Canadian customers from international manufacturing facilities, products should be sent to Canadian distribution centres which results in much higher transportation costs comparing to the base case. Also due to the larger distances to the distribution centres the stochastic sales to the customers can not be done sooner than period 3 which results in the decrease in the expected average service level and complete lost sales in the first two periods.

Case	Total production cost	Total transportation cost	Total lost sale cost	Total overstock cost	Total raw material cost
I. Base case	97104.06	700800	508750	207500	1310260
II. Full outsourcing	8719.97	1159306	1087750	175000	927514
III. No outsourcing	123450	659370	508750	207500	1380510

Table 2. Comparison of the costs

5. Conclusion

In this chapter we presented an integrated optimization model to provide a decision support tool for managers. The logistic decisions consist of the determination of the suppliers and the capacity of each potential manufacturing facility, and also the optimization of the material flow among all the production, distribution and consumer zones in global supply chains with uncertain demand. The model is among the few models to date than can be conveniently customized to capture real world supply chains with different characteristics. A hypothetical example was given to assess whether it is better for a company to go global or to expand its existing facilities and it was shown that outsourcing the whole production to the countries with lowest production costs is not always the best case and failing to consider several other cost factors might lead to much higher overall costs and lower service levels. It was also concluded that even the supply chain configurations leading to lower costs are not always the most suitable settings and the managers should not ignore the tradeoffs between the cost and the other objectives such as the service level in our case.

Future expansions to our model can be the addition of more global factors to make it more realistic and also suggesting solution procedures to solve larger instances of the model.

Appendix A

Notation
Sets and indices

j, k, l	Nodes (domestic and international suppliers, plants, distribution centres, and customers) in the supply network
p	Production quantity range
s	Individual realization scenarios of the stochastic variable (low, medium, high)
js	Joint realization scenarios of the stochastic variables
r	Transportation modes
i	Raw materials
t	Time periods

Decision variables

x_{ijkt}	Quantity of raw material i purchased from supplier j for plant k in period t
Q_{jt}	Quantity of products produced at plant j in period t
Q_{jpt}	Quantity of products produced at range p at plant j in period t
Q_{jkrt}	Quantity of products shipped from node j to node k via mode r in period t
Cap_{jt}	Capacity level at plant j in period t
$u1_{jt}$	Capacity level at plant j in period t when capacity in expanded
$u2_{jt}$	Capacity level at plant j in period t when capacity in not expanded
I_{jt}	Ending inventory level at node j in period t
$Sales_{l,t,js}^s$	Stochastic sales to customer zone l in period t under joint scenario js
$Lostsale_{l,t,js}^s$	Stochastic lost sale at customer zone l in period t under joint scenario js
$Overstock_{l,t,js}^s$	Stochastic overstock at the customer zone l in period t under joint scenario js

V_{jpt}	Binary variable showing the interval to which the production amount belongs
y_{jt}	Binary variable showing if capacity expansion occurs at plant j in period t

Other notation

RC	Total raw material cost
PC	Total production cost at domestic plants
PCI	Total production cost at international plants
TC	Total transportation cost at the local plants
TCI	Total transportation cost at the international plants
TCD	Total transportation cost at the distribution centres
$TCapCj$	Total capacity expansion cost at local plants
$TCapCI$	Total capacity expansion cost at international plants
$TCapC$	Total capacity expansion costs
$TarC$	Total tariff cost
IC	Total inventory cost
ASL	Stochastic average service level to be maximized

Parameters

$demand_{l,js}^s$	Possible outcome of the stochastic demand at customer zone l under joint scenario js
ξ_{js}	Joint probability of the possible outcome of the demand under joint scenario js
N_{js}	Total number of joint scenarios
C_{ijk}	The unit price of raw material i from supplier j for plant k
\overline{Q}_p	Upper bound for interval p of the production amount
\overline{UPC}_p	Production cost which corresponds to interval p of the production amount

NR_j	Total number of sub-ranges for production amount
UTC_{jkr}	Unit transportation cost from node j to node k via transportation mode r
LT_{jkr}	Lead-time of transportation from node j to node k via transportation mode r
PI	Pipeline inventory cost per period per unit of product
$Cap\ max_j$	Maximum available capacity at plant j
$CapC_j$	Unit capacity expansion cost at plant j
$Tarrif_j$	Tariff rate from international plant j to domestic distribution centres
UIC_j	Unit inventory cost at node j
LC	Lost sale penalty
OC	Overstocking penalty
E_{jt}	Exchange rate of the currency of the international plant j
α_i	The number of units of raw material i required to produce one unit of the product
β_{ij}	The amount of supplier j 's internal resource required to produce one unit raw material i
q_j	The capacity of supplier j
\mathcal{E}	Minimum required expected average service level
I	Total number of raw material types
T	Total number of planning periods
M	A big natural value

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Traditionally supply chain management has meant factories, assembly lines, warehouses, transportation vehicles, and time sheets. Modern supply chain management is a highly complex, multidimensional problem set with virtually endless number of variables for optimization. An Internet enabled supply chain may have just-in-time delivery, precise inventory visibility, and up-to-the-minute distribution-tracking capabilities. Technology advances have enabled supply chains to become strategic weapons that can help avoid disasters, lower costs, and make money. From internal enterprise processes to external business transactions with suppliers, transporters, channels and end-users marks the wide range of challenges researchers have to handle. The aim of this book is at revealing and illustrating this diversity in terms of scientific and theoretical fundamentals, prevailing concepts as well as current practical applications.

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