A Multi-Period Mixed Integer Programming Model for the International Plant Location Problem

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ABSTRACT

A company's ability to supply products to markets worldwide with responsiveness and efficiency depends on the amount of flexibility its network of plants has to serve markets other than the local ones. With this flexibility comes the challenge of which plants to open or close in the face of the changing markets conditions. With known plant capacities and market demands, sale prices by country, transportation costs, production and inventory costs, export incentives and import duties of the various countries, the proposed mathematical model determines which set of plants to open, and the quantities that plants ship to each country in each time period so that total supply chain profit is maximized.

INTRODUCTION

In today's global economy where virtually the same products are sold to consumers all over the world, international facility location decisions are considered by many researchers to have a profound impact on a company's performance. This is so because the global network of facilities defines the physical constraints within which production, inventory, transportation, and information are managed to deliver product to markets. Strategically located facilities can help decrease supply chain cost and increase responsiveness. However, as market conditions change and the current supply chain configuration becomes too expensive or provides poor responsiveness, the supply chain networks need to be redesigned to improve supply chain performance.

Global supply chain network decisions are not obvious and require understanding the trade-offs between many conflicting factors such as the location of customers, and market sizes worldwide, the location, capacity, and cost structures of potential production facilities, the length of the global supply chain pipeline in distance and time, the transit time and cost of the various modes of transportation, as well as local content regulations, export incentives, and duty rates of the various countries. Hence, the importance of developing methodologies capable of integrating these factors within the same decision framework.

For a multinational company that is either facing changing market dynamics due to global competition or expecting relevant costs to change over time as a result of new technological advances and other economic conditions the multi-period international plant location problem (MIPLP) is an important decision problem. This problem involves decisions on the number of plants to open or close, their location in the world, the types of products and corresponding quantities each facility produces, the markets or countries each facility serves as well as the quantities shipped from each plant to each market. The objective is to reconfigure the global supply chain network in response to expected changes in customer demands, and production and transportation costs from and to the various countries under consideration over the multi-period planning horizon in such a way to maximize profits and minimize costs.

MODEL DEVELOPMENT

Notation

Primary Sets

$P =$ Set of products

$C =$ Set of countries

$F =$ Set of production facilities

$T =$ Set of time periods in the planning horizon

Induced Index Sets

$P_c =$ Set of products demanded by customers in country *c*,

$P_f =$ Set of products that can be manufactured at facility *f*,

$F_p =$ Set of facilities capable of producing product *p*,

$F_c =$ Set of production facilities in country *c*,

Cost Data

$C_{pft} =$ Fixed cost of producing product *p* at facility *f* in period *t*,

$F_{ft} =$ Fixed cost of operating facility *f* in period *t*,

$L_{ft} =$ Cost of closing facility *f* in period *t*,

$T_{pfct} =$ Transportation cost of one unit of product *p* from facility *f* to country *c* in period *t*,

$V_{pft} =$ Unit variable production cost of product *p* at facility *f* in period *t*,

$H_{pft} =$ Cost of holding one unit of product *p* in inventory at facility *f* throughout period *t*,

$SP_{pct} =$ Unit selling price of product *p* in country *c* in period *t*,

$IM_{pct} =$ Duty fee for importing one unit of product *p* into country *c* in period *t*,

$EX_{pft} =$ Monetary incentive given by the host country of facility *f* for exporting one unit of product *p* to other countries in period *t*,

$R_{pct} =$ The gross revenue realized from the sale of one unit of product *p* in country *c* during period *t*. This is the sale price of one unit of product *p* in country *c* plus its corresponding export incentive from the country hosting facility *f* minus its transportation cost, and import duty into country *c* in time period *t* (i.e. $R_{pct} = SP_{pct} + EX_{pft} - T_{pfct} - IM_{pct}$). Observe that R_{pct} does not reflect production and inventory costs. These costs will be considered separately in the objective function.

Supply/Demand Data

$D_{pct} =$ Demand of product *p* (in units) from country *c* in period *t*,

$S_{pft} =$ Production capacity of product *p* at facility *f* in period *t*, *Decision Variables*

$X_{pfct}=$ Units of product *p* shipped from facility *f* to country *c* in period *t*,

$Y_{pft}=$ Units of product *p* produced at facility *f* in period *t*,

$I_{pft}=$ Units of product *p* held in inventory at facility *f* at the end of period *t*,

$$Z_{pft}=\begin{cases}1, \text{if product } p \text{ is produced in facility } f \text{ during period } t;\\ 0, \text{otherwise.}\end{cases}$$

$$Q_{ft}=\begin{cases}1, \text{if facility } f \text{ is open for production in period } t;\\ 0, \text{otherwise.}\end{cases}$$

$$U_{ft}=\begin{cases}1, \text{if facility } f \text{ is closed in period } t;\\ 0, \text{otherwise.}\end{cases}$$

Problem Formulation

Max

$$\mathcal{Z}=\sum_{t\in T}[\sum_{p\in P}\sum_{f\in F_p}\sum_{c\in C}R_{pct}\,X_{pfct}-\sum_{f\in F}(F_{ft}\,Q_{ft}+L_{ft}U_{ft})-\sum_{p\in P}\sum_{f\in F_p}C_{pft}\,Z_{pft}-\sum_{p\in P}\sum_{f\in F_p}V_{pft}\,Y_{pft}-\sum_{p\in P}\sum_{f\in F_p}H_{pft}\,I_{pft}] \quad (1)$$

Subject to:

$$\sum_{f\in F_p}X_{pfct}\le D_{pct}, \qquad p\in P, c\in C, t\in T; \quad (2)$$

$$Y_{pft}+I_{pf,t-1}=\sum_{c\in C}X_{pfct}+I_{pft}, \qquad p\in P, f\in F_p, t\in T; \quad (3)$$

$$Y_{pft}\le S_{pft}\,Z_{pft}, \qquad p\in P, f\in F_p, t\in T; \quad (4)$$

$$Z_{pft}\le Q_{ft}, \qquad p\in P, f\in F_p, t\in T; \quad (5)$$

$$Q_{ft}+U_{ft}=1, \qquad f\in F, t\in T; \quad (6)$$

$$Z_{pft}, Q_{ft}, U_{ft}=\{0,1\}, \qquad p\in P, f\in F, t\in T; \quad (7)$$

$$X_{pfct}, Y_{pft}\ge 0, \qquad p\in P, f\in F_p, c\in C, t\in T. \quad (8)$$

Constraint set (2) ensures that total shipments from open plants for each product in each time period be no larger than the worldwide demand for such a product in that time period. In order to account for the possibility of not serving unprofitable markets, this constraint does not enforce the fulfillment of all market demands. Constraint (3) imposes product flow conservation among production, inventory, and shipping variables for each production facility during every time period. Constraint set (4) requires that the total quantity of product *p* produced at facility *f* in period *t* does not exceed the production capacity of that product at that facility. Constraint set (5) states the condition that product *p* may be produced at facility *f* in period *t* only if that facility is open for production during that time period. Constraint (6) enforces the logical condition that in period *t* facility *f* is either open or closed. Constraints (7) and (8) respectively ensure integrality and nonnegativity on the decision variables. Equation (1) expresses the objective of the MIPLP model as maximization of the global supply profits over the planning horizon. This equation incorporates gross revenues, fixed costs of opening and closing facilities, and those of producing specific products in those facilities, variable production costs, and inventory holding costs. Gross Revenues include the selling price minus the cost of transporting the product from a given facility where it is produced to the country where it is sold, and are adjusted for such factors as export incentives and import duties in both the exporting and the importing countries. *Full paper available upon request*.