Impact of Transportation Costs on Facility Location Decisions

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ABSTRACT

Facility location has received great attention in the past few years. Researchers have focused on many aspects of the location identification and selection decision. Transportation cost form an important part of the cost structure of any facility location decision. In this paper we present a facility location model that studies the impact of cumulative transportation costs on the decision.

INTRODUCTION

In the last three decades internationalization has been the driving force behind global trade and commercialization. Greater liberalization of trade policies and a move towards open borders has greatly fueled this push. Global firms seek to locate facilities in regions of competitive advantage. Consequently both researchers and practitioners have focused on this trend and there has been a tremendous increase in analytical studies in the field of global facility location

Typically when researchers have included transportation costs as part of their facility location models they have focused on cost from the facility to markets. (Mohamed, 1999; Syam, 2002; Bhutta, 2003). This paper develops a facility location model and focuses on the impact that transportation costs have on facility location decisions, the paper is unique as it not only considers transportation costs from the facility to markets but also suppliers to facilities.

With the global business environment changing with increased security concerns the need remains to carefully reexamine costs especially those related to transportation/logistics. This paper will attempt to better understand the relationship between these costs and the desire of firms to operate globally.

The paper is organized as follows; in Section 2 we provide a brief over view of relevant existing literature; Section 3 begins will the proposed model and a brief discussion on the solution; and Section 4 presents the summary to the paper.

LITERATURE REVIEW & BACKGROUND

Significant amount of literature (Czinoka et al., 1994; Hodder et al., 1985; Kotabe, 1994; Syam, 2002) already exists that focuses on the various aspects of a firm's operations including production planning, distribution, and investment opportunities. Production planning decisions include product and quantity mix decisions incorporating issues such as capacity and production planning, and labor- hiring and inventory levels. Distribution decisions include which suppliers to select for which part/material and which distribution center will cater to the demand of which market. Financial decisions include - investment opportunities, capital borrowing decisions, and other related decisions.

However, scanty work is in evidence, which attempts to combine and provide a unified model for the production, location, distribution and investment decisions. Especially in the international business arena, one cannot consider the various risk factors independently, but has to look at the aggregate impact of these factors. Another limitation of current literature is that it is explicitly concerned with investment decisions at the operational level and rarely does it incorporate strategic, international and/or supply chain issues (Canel et al., 1994). A review of literature reveals that most of the research done on integrative modeling has been on domestic firms (Meijboom et al., 1997; UN, 1973) and only recently have researchers started to addresses various aspects of multinational corporation's production, distribution, and location decisions. (Allen, 1991; Bijayananda, 1994; Canel et al., 1994;, Filipo, 2000; Bhutta et al., 2003). Interested readers can review Bhutta (2004) which provides an excellent review on the integrated modeling literature on facility location. Various factors have been identified in literature to incorporate in facility location modeling, Table 1depicts some of these factors and the researches who have published about them.

Factors	Selected Researchers (year of publication)
Market Factors	Rao, (1999); Mallen, (1994)
Customers & Competition	Braunerhjelm, (2000); Roberts, (1999) ; Canel et al., (1994)
Powers and Prestige	Braunerhjelm, (2000); Frearing, (1999)
Manufacturing Factors	Hadjinicola (2002); Mohamed (1999)
Low Cost Producers	Frearing, (1999); Ellram, (1995)
Exploitation of R&D	Roberts, (1999)
Economies of Scale	Roberts, (1999); Choi, (1994)
Synergy	Braunerhjelm, (2000); Elsass, (1999) ; Canel et al., (1994)
International Regulations	Braunerhjelm, (2000); Canel et al., (1994); Schinasi, (1989)
Reactive vs. Proactive	Braunerhjelm, (2000); Canel et al., (1994); Schinasi, (1989)
Government Incentives	Flipo, (2000)
Taxes	Macdonald, (2000)
Trade Barriers & Regulations	Braunerhjelm, (2000); Macdonald, (2000); Canel et al., (1994); Roberts, (1999)

Table 1: Salient factors in Facility Location Modeling

To summarize, companies in various stages of globalization incorporate many factors in their operational decision making, consideration of these factors helps formulate optimal decisions as these factors may impact the profitability of the firm.

Several techniques have been used in the past to solve the facility location models including; dynamic programming by Pomper (1974); break-even analysis by Jucker (1977); quadratic programming approach by Hodder (1985); and Mohamed (1999) and Bhutta (2003) used a mixed integer linear programming approach to the facility location problem. Other techniques such as fuzzy set theory (Bijayananda, 1994) and various other heuristics (Haug, 1992) have also been used.

In this paper we propose an integrated facility location model incorporating the operational aspects of a firm and focusing on the “in-coming” and “out-going” transportation costs. The model considers ‘j’ products, ‘m’ markets, ‘f’ facilities, and ‘t’ time periods to facilitate the understanding and applicability, the model is not intrinsically limited to a specific scale.

PROPOSED MODEL

The proposed model is in the form of a mixed integer linear programming formulation. The model depicts considers a firm that is considering expanding its facilities globally. The firm produces multiple products and can if needed increase/decrease capacity to meet market conditions. The formulation is setup as a profit maximization problem with capacity, quantity of products produced and the amount of products shipped from each facility as well as the raw material required as the decision variables. The decision variables are presented in Table 1 and the indices and parameters are depicted in Table 2.

Decision Variables	Description of the Variables
CAP_{ft}	Capacity of facility ‘f’ in period ‘t’
S_{rft}	Amount of raw material ‘r’ supplied to facility ‘f’ at time ‘t’
A_{jfmt}	Amount of product ‘j’ shipped from facility ‘f’ to market ‘m’ in period ‘t’
Q_{jft}	Quantity of product ‘j’ produced in facility ‘f’ in period ‘t’

Table 1. Decision Variables

Cap_{ft} and Aj_{fmt} are not restricted to integer values. Moreover, the CAP_{ft} variable is generally considered as continuous variables since they are measured in terms of dollars and cents

Variables	Description of the Variables
J	Set of products {1,2,3,…..,j……..,J}
F	Set of facilities {1, 2, 3,….,f,….,F}
M	Set of markets {1, 2, 3,….,m,….,M}
T	Set of time periods {1, 2, 3,….,t,…..,T}
R	Set of raw materials
D_{jmt}	Demand for product ‘j’ for market ‘m’ in period ‘t’
C_{jft}	Manufacturing cost/unit of product ‘j’ in facility ‘f’ in period ‘t’
r_{jmt}	Revenue/unit of product ‘j’ in market ‘m’ in time ‘t’
h_{jft}	Unit inventory holding cost of product ‘j’ in facility ‘f’ in period ‘t’
U_{ft}	Unit capacity changing cost in facility ‘f’ in period ‘t’

tc_{rft}	Transportation Cost per unit for raw material ‘r’ to facility ‘f’ in period ‘t’
s_{jfmt}	Unit shipping cost of product ‘j’ from facility f to market m in period ‘t’
I_{jft}	Ending inventory of product ‘j’ in facility ‘f’ in period ‘t’
RI_{rft}	Ending raw material inventory of raw material ‘r’ in facility ‘f’ in period ‘t’
RP_{rt}	Unit price of raw material ‘r’ in facility ‘f’ in period ‘t’
REQ_{jr}	Amount of raw material ‘r’ required to produce one unit of product ‘j’
$MCOST_{ft}$	Manufacturing cost at facility ‘f’ in time period ‘t’
$IHCOST_{ft}$	Inventory holding cost of facility ‘f’ in period ‘t’
$OpeningCost_{ft}$	Cost of Opening facility ‘f’ in period‘t’
$FixedCost_{ft}$	Fixed Cost to open a facility ‘f’ in period ‘t’
$ClosingCost_{ft}$	Cost of closing a facility ‘f’ in period‘t’
TC_{ft}^{out}	Total Outbound Transportation Cost from facility ‘f’ in period‘t’
TC_{ft}^{in}	Total Inbound Transportation Cost to facility ‘f’ in period ‘t’
p_j	Processing capacity for product ‘j’
α	Constant
β	Constant to provide cushion to meet demand

Table 2. Indices and Parameters

Using the parameters and indices defined above, the complete model is presented below. A description and discussion of each of the constraints of the model follows presentation of the complete model.

Minimize Cost

$$\sum_f \sum_t OpeningCost_{ft} + \sum_f \sum_t ClosingCost_{ft} + \sum_f \sum_t MCost_{ft} + \sum_f \sum_t TC_{ft}^{in} + \sum_f \sum_t TC_{ft}^{out} + \sum_f \sum_t IHCost_{ft} + \sum_f \sum_t TRCost_{ft} \quad \textbf{(1)}$$

Subject to:

$$OpeningCost_{ft} = \left(Cap_{ft} - Cap_{f(t-1)}\right) \times U_{ft} \qquad \forall\ f, t \qquad \textbf{(2)}$$

$$ClosingCost_{ft} = OpeningCost_{ft} \times \alpha \qquad \forall \text{ f, t} \qquad \textbf{(3)}$$

$$MCost_{ft} = \sum_{j} \left(C_{jft} \times Q_{jft} \right) + FixedCost_{ft} \qquad \forall \text{ f, t} \qquad \textbf{(4)}$$

$$IHCost_{ft} = \sum_{j} (I_{jft} \times h_{jft}) \qquad \forall \text{ f, t} \qquad \textbf{(5)}$$

$$\sum_{r} TRCost = S_{rft} \times RP_{rt} \qquad \forall \text{ f, t} \qquad \textbf{(6)}$$

$$TC_{ft}^{in} = \sum_{r} \left(tc_{rft} * S_{rft} \right) \qquad \forall \text{ f, t} \qquad \textbf{(7)}$$

$$TC_{ft}^{out} = \sum_{j} \sum_{m} \left(s_{jfmt} * A_{jfmt} \right) \qquad \forall \text{ j, f, t} \qquad \textbf{(8)}$$

$$Cap_{ft} \geq \sum_{j} \left(p_{j} \times Q_{jft} \right) \qquad \forall \text{ f, t} \qquad \textbf{(9)}$$

$$\sum_{f} Cap_{ft} \geq \sum_{j} \sum_{m} D_{jmt} \times \beta \qquad \forall \text{ r,f,t} \qquad \textbf{(10)}$$

$$Cap_{ft} \geq Cap_{f(t-1)} \qquad \forall \text{ j,r,f,t} \qquad \textbf{(11)}$$

$$\sum_{f} A_{jfmt} \geq D_{jmt} \qquad \forall \text{ f, t} \qquad \textbf{(12)}$$

$$I_{jf(t-1)} + Q_{jft} = \sum_{m} \left(A_{jfmt} \right) + I_{jft} \qquad \forall \text{ j, m, t} \qquad \textbf{(13)}$$

$$RI_{rf(t-1)} + S_{rft} = \sum_{j} \left(Q_{jft} * REQ_{jr} \right) + RI_{rft} \qquad \forall \text{ t} \qquad \textbf{(14)}$$

Q is integer **(15)**

All variables ≥ 0 **(16)**

The objective function (1) minimizes costs considered in the model. Constraint equations (2) – (8) depict cost constraints setting up the Expansion, Closing, Manufacturing, Inventory; Transportation–In and Transportation—Out costs; Constraint equation (9)–(11) link capacity available with the processing requirements of products, market demand and capacity of previous period respectively; Constraint equations (12) – (14) insure that the amount produced at least meets demand, and is no more than the amount shipped plus any left over inventory, amount received from suppliers plus any existing inventory meets production requirements and amount received from suppliers plus any existing inventory, amount respectively. Constraint equations (15) – (16) are basic integer and non-negativity constraints.

To validate our model, we implemented it with random data within two linear programming software packages—LIPSOL[1] (a Matlab plugin available over the WWW) and the linear programming component of SAS[2]—on a Pentium 4 CPU with 512 KB RAM. The model was solved to check for validity and mathematical accuracy using hypothetical data. The authors are in the process of gathering real time data to perform realistic scenarios. This will be the focus of future research.

SUMMARY

Past research shows various modeling techniques adopted by researchers to benefit the understanding of the interactions of various factors on production, location and distribution decisions of firms. This paper sought to focus on the transportation decisions and the impact of their costs on the facility location decisions. We present a model that considered various variables related to the facility location decision and formulated it as a mixed integer linear program.

Further research by the authors aims to incorporate backward integration of the model to include supplier selection decisions to help locate facilities in regions which not only cater to the demand side issues (such as, rapid product launches, proximity to demand centers) but also takes into account the supply end of the equation (e.g. human resource, raw material availability, infra-structure, etc).

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[1] http://www.caam.rice.edu/~zhang/lipsol/

[2] http://www.sas.com/technologies/analytics/optimization/

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