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# Integration of financial statement analysis in the optimal design of supply chain networks under demand uncertainty

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ABSTRACT

Models that aim to optimize the design of supply chain networks have become a mainstream in the supply chain literature. This paper aims to fill a gap in the literature by introducing a mathematical model that integrates financial considerations with supply chain design decisions under demand uncertainty. The proposed Mixed-Integer Linear Programming (MILP) problem enchases financial statement analysis through financial ratios and demand uncertainty through scenario analysis. The applicability of the model is illustrated by using a case study along with a sensitivity analysis on financial parameters expressing the business environment. The model could be used as an effective and convenient strategic decision tool by supply chain managers.



## 1. Introduction

During the last decade of the 20th century rapid changes occurred in the business environment. Competition among companies in all their operational functions, from raw material sourcing to customer service, has dramatically increased. Companies have extended their strategic focus in the global market. Cost and price benefits had been scattered across various countries and regions of the world and had pushed companies to seize upon these opportunities. Hence, companies were forced to manage their operations over the limited "unique enterprise" framework. Orientation to external environment is a medium that enables companies to obtain the necessary sources and abilities (Spekman et al., 1998). These developments have driven to the evolution of "supply chain management" (SCM) as companies have realized that they cannot operate individually anymore, but only as parts of a complicated business operations chain (Tan et al., 1998).

Organizations, which constitute a supply chain network (SCN), interact through continuous and two-sided connections that create added value in products (Mentzer et al., 2001). These networks have an undefined number of echelons and stages while their main operations involve purchasing of raw materials from suppliers, production, transportation and storage of products, inventory management, and distribution of products to customers (Simchi-Levi et al., 2000).

Part of the planning process in SCM aims at finding the best possible supply chain configuration. These decisions are considered strategic because of their long time horizon and are tackled with facility location models. However, by considering certain aspects of the supply chain environment, these models are adequately capable to support the Supply Chain Network Design (SCND) phase (Melo et al., 2009). Moreover, dynamic facility location models, where the decisions are spread out over a long-term planning horizon and the decision variables are time-dependent, are becoming more compatible to track the dynamics of complex supply chains (Thanh et al., 2008).

Since companies recognized the potential competitive advantages, gained through a holistic management of their supply chain, the academic community has been developing several models that describe their design and operation. These models support management staff in both strategic and tactical decisions regarding management of supply and distribution networks. Although numerous successful models have been developed for the design and operation of supply chains, their vast majority ignores decisions involving revenues, marketing campaigns, hedging against uncertainties, investment planning, and other corporate financial decisions (Shapiro, 2004). Financial factors are among the issues that have a strong impact on the configuration of global supply chains (Melo et al., 2009). Financial globalization factors such as corporate income taxes, transfer prices, currency exchange rates, are some of the key components that a supply chain design model in the delocalization context should take into account (Hammami et al., 2008). Integration of financial aspects in these models allows for the systematic assessment of the impact of production decisions in the financial operation and further selects their ideal combination thus providing a competitive advantage in the company (Guillén et al., 2006). Inclusion of financial considerations in supply chain models is particularly advised for capital intensive activities (continuous processes, heavy industrial equipments, etc.).

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## Nomenclature

*Indices*

- $e$ production resources (equipment, manpower, utilities, etc.)
- $i$ products
- $j$ plants
- $k$ possible distribution centers
- $l$ customer zones
- $m$ possible warehouses
- $s$ product demand scenario
- $t$ time period

*Sets*

- $K^{SS}$ set of distribution centers that should be supplied by a single warehouse
- $L^{SS}$ set of customer zones that should be supplied by a single distribution center

*Parameters*

- $C_{im}^{WH}$ unit handling cost for product $i$ at warehouse $m$
- $C_{ik}^{DH}$ unit handling cost for product $i$ at distribution center $k$
- $C_m^{W}$ annualized fixed cost of establishing warehouse at location $m$
- $C_k^{D}$ annualized fixed cost of establishing distribution center at location $k$
- $C_{ij}^{P}$ unit production cost for product $i$ at plant $j$
- $C_{ijm}^{TR}$ unit transportation cost of product $i$ transferred from plant $j$ to warehouse $m$
- $C_{imk}^{TR}$ unit transportation cost of product $i$ transferred from warehouse $m$ to distribution center $k$
- $C_{ikl}^{TR}$ unit transportation cost of product $i$ transferred from distribution center $k$ to customer zone $l$
- $C_{ij}^{I}$ unit inventory cost of product $i$ at plant $j$
- $C_{im}^{I}$ unit inventory cost of product $i$ at warehouse $m$
- $C_{ik}^{I}$ unit inventory cost of product $i$ at distribution center $k$
- $\mathrm{CFP}_t$ percent of net operating profits after taxes that are connected with cash flow at the end of period $t$
- $\mathrm{CCR}_t$ minimum bound for cash coverage ratio at the end of time period $t$
- $\mathrm{CR}_t$ minimum bound for cash ratio at the end of time period $t$
- $\mathrm{CUR}_t$ minimum bound for current ratio at the end of time period $t$
- $D_k^{max}$ maximum capacity of distribution center $k$
- $D_k^{min}$ minimum capacity of distribution center $k$
- DCMFM days corresponded to material flow measurement scale
- $\mathrm{DM}_{ilt}^{[s]}$ demand for product $i$ from customer zone $l$ during time period $t$ under scenario $s$
- $\mathrm{DER}_t$ upper bound for debt–equity ratio at the end of time period $t$
- $\mathrm{DR}_t$ depreciation rate at the end of time period $t$
- $\mathrm{FATR}_t$ lower bound for fixed assets turnover ratio at the end of time period $t$
- $I_{ijt}^{[s],min}$ minimum inventory of product $i$ held in plant $j$ at the end of time period $t$ under scenario $s$
- $I_{imt}^{[s],min}$ minimum inventory of product $i$ held in warehouse $m$ at the end of time period $t$ under scenario $s$
- $I_{ikt}^{[s],min}$ minimum inventory of product $i$ held in distribution center $k$ at the end of time period $t$ under scenario $s$
- $\mathrm{LTDR}_t$ upper bound for long-term debt ratio at the end of time period $t$
- $\mathrm{LTR}_t$ long-term interest rate at the end of time period $t$
- $n^{DC}$ minimum inventory held at distribution centers expressed in terms of number of days equivalent of materials handled
- $n^{W}$ minimum inventory held at warehouses expressed in terms of number of days equivalent of materials handled
- $n^{P}$ minimum inventory held at production plants expressed in terms of number of days equivalent of materials handled
- NS number of product demand scenarios
- $P_{ijt}^{[s],max}$ maximum production capacity of plant $j$ for product $i$ during time period $t$ under scenario $s$
- $P_{ijt}^{[s],min}$ minimum production capacity of plant $j$ for product $i$ during time period $t$ under scenario $s$
- $\mathrm{PMR}_t$ lower bound for profit margin ratio at the end of time period $t$
- $\mathrm{PRICE}_{ilt}^{[s]}$ price for product $i$ for customer zone $l$ during time period $t$ under scenario $s$
- $Q_{jm}^{min}$ minimum rate of flow of material that can practically and economically be transferred from plant $j$ to warehouse $m$
- $Q_{mk}^{min}$ minimum rate of flow of material that can practically and economically be transferred from warehouse $m$ to distribution center $k$
- $Q_{kl}^{min}$ minimum rate of flow of material that can practically and economically be transferred from distribution center $k$ to customer zone $l$
- $Q_{ijm}^{[s],max}$ maximum rate of flow of product $i$ that can be transferred from plant $j$ to warehouse $m$ under scenario $s$
- $Q_{imk}^{[s],max}$ maximum rate of flow of product $i$ that can be transferred from warehouse $m$ to distribution center $k$ under scenario $s$
- $Q_{ikl}^{[s],max}$ maximum rate of flow of product $i$ that can be transferred from distribution center $k$ to customer zone $l$ under scenario $s$
- $\mathrm{QR}_t$ lower bound for quick ratio at the end of time period $t$
- $R_{je}$ total rate of availability of resource $e$ at plant $j$
- $\mathrm{ROAR}_t$ lower bound for return on assets ratio at the end of time period $t$
- $\mathrm{ROER}_t$ lower bound for return on equity ratio at the end of time period $t$
- $\mathrm{RTR}_t$ lower bound for receivables turnover ratio at the end of time period $t$
- $\mathrm{STR}_t$ short-term interest rate at the end of time period $t$
- $\mathrm{TDR}_t$ upper bound for total debt ratio at the end of time period $t$
- $\mathrm{TR}_t$ tax rate at the end of time period $t$
- $W_m^{max}$ maximum capacity of warehouse $m$
- $W_m^{min}$ minimum capacity of warehouse $m$
- $\mathrm{WACC}_t$ weighed average cost of all invested capital at the end of time period $t$
- $\Delta T_t$ duration of time period $t$

*Continuous Variables*

- $C_t$ cash at the end of time period $t$
- $\mathrm{COGS}_t$ cost of goods sold at the end of time period $t$
- $\mathrm{CA}_t$ current assets at the end of time period $t$
- $D_k$ capacity of distribution center $k$
- $\mathrm{DPR}_t$ depreciation at the end of time period $t$
- $\mathrm{EBIT}_t$ earning before interests and taxes at the end of time period $t$