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An integrated multi-objective supply chain network and competitive facility location model

Canser Bilir [a,*], Sule Onsel Ekici [b], Fusun Ulengin [c]

[a] Istanbul S. Zaim University, Industrial Engineering Department, Halkali Cd. Kucukcekmece, 34303 Istanbul, Turkey
[b] Dogus University, Engineering Faculty, Industrial Engineering Department, Zeamet Sok., No: 21 Kadikoy, 34722 İstanbul, Turkey
[c] Sabanci University, Sabanci School of Management, Orta Mah. Universite Cad. No: 27 Orhanli – Tuzla, 34956 Istanbul, Turkey

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ABSTRACT

In this study, a multi-objective supply chain (SC) network optimization model based on the joint SC network optimization and competitive facility location models is proposed to analyse the results of ignoring the impacts of SC network decisions on customer demand. The objectives utilized in the model are profit maximization, sales maximization and SC risk minimization. The unique unknown variable within the model is the demand. The demand at each customer zone is assumed to be determined by price and the utility function. The utility function is defined as the availability of same-day transportation from the distribution centre (DC) to the customer zone. The application of the proposed model is illustrated through a real-world problem and is solved as single and multi-objective models. The results of single and multi-objective models are subsequently compared. After solving the problem, a sensitivity analysis is also conducted to test the applicability of the model with respect to various parameter coefficients, such as price elasticity, one–day replenishment coverage impact, risk factors (disruption probabilities) and the relative weights of the objectives.

1. Introduction

The optimization of SC networks plays a key role in determining the competitiveness of the whole SC. Therefore, during the last two decades, an increasing number of studies have focused on the optimization of the overall SC network. However, in most of these optimization studies, the structure of the SC network is considerably simplified (e.g., a single product and a single location layer are usually assumed), and there is still a need for more comprehensive models that simultaneously capture many aspects that are relevant to real-world problems such as demand dynamics on the market.

Facility location decisions—more specifically, decisions on the physical network structure of a SC network—are important factors affecting chain's competitiveness, especially for the SCs serving retail markets. However, SC network optimization models in the current literature ignore the impacts of SC network decisions on customer demand. Nevertheless, competitive facility location problems model only the distribution part of the SC, even though they have certain characteristics of SC networks and analyse the rival chains existing on the market (Bilir, Ekici, & Sweeney, 2015).

In this study, a new model has been proposed in which the concept of SC network optimization modelling is incorporated with competitive facility location factors (e.g., changing demands that are dependent not only on price but also on customer service related functions). The aim of this model is to include the impact of a SC's physical network structure on customer demand.

The remainder of the paper is organized as follows: the next section provides a brief literature review. Section 3 focuses on the proposed model as well as its objectives, variables, and parameters. Section 4 defines a real-world problem to which the proposed model is applied. Section 5 provides the results of the model that is applied to a real-world scenario. The paper ends with final conclusions of the study and provides further research suggestions.

2. Literature review

In order to identify different characteristics of the various models and common trends, we conducted a comprehensive literature of recently developed (from 2009 to 2013) SC network optimization models. In this review, our focus was on identifying studies that included a strategic-level SCN model. Models that considered

* Corresponding author.
E-mail addresses: canser.bilir@izu.edu.tr (C. Bilir), sonsel@dogus.edu.tr (S.O. Ekici), fulengin@sabanciuniv.edu (F. Ulengin).

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the reconfiguration or relocation of the SCN nodes and arcs (0–1 decisions) are considered as strategic-level models.

To generate a list of relevant articles published between 2009 and 2013, "SC network modelling" was entered as a search term in the Science Direct database. This generated an initial list of articles, from which 72 that were published only in the most relevant journals and included strategic level decision variables were selected and analysed.

Supply chains are dynamic networks consisting of multiple transaction points with complex transportation, information transactions and financial transactions between entities. Therefore, SC modelling involves several conflicting objectives, at both the individual entity and SC levels. Our survey on SC network model objectives showed that the majority of SC network optimization models are solely based on cost minimization (e.g., Lundin, 2012; Melo, Nickel, & Saldanha-da-Gama, 2012; Nagurney, Ladimer, & Nagurney, 2012) or profit maximization objectives (e.g., Kabak & Ulengin, 2011; Rezapour & Farahani, 2010; Yamada, Imai, Nakamura, & Taniguchi, 2011), even though the number of multi-objective models is increasing and there appears to have been a major shift from cost minimization to profit maximization objectives (Bilir et al., 2015).

Indeed, 24% of studies in the SC literature from 2009 to 2014 feature multi-objective functions. When compared to 9% of the articles reviewed by Melo, Nickel, and Saldanha-da-Gama (2009), it can be concluded that multi-objective models are becoming increasingly popular. Multi-objective models typically include a cost minimization or profit maximization function, together with customer service, environmental effects or risk mitigation related objectives (e.g., Akgul, Shah, & Papageorgiou, 2012; Olivares-Benitez, Ríos-Mercado, & González-Velarde, 2013; Prakash, Chan, Liao, & Deshmukh, 2012; Shankar, Basavarajappa, Chen, & Kadadevaramath 2013).

The existence of competition within the market (both among firms and via other SCs providing the same or substitutable goods) is an important factor that must be considered when designing a SC network.

The literature survey that we have conducted regarding competition modelling for SCs identified only seven papers (Masoumi, Yu, & Nagurney, 2012; Nagurney, 2010; Nagurney & Yu, 2012; Rezapour & Farahani, 2010; Rezapour, Farahani, Ghodsipou, & Abdollahzadeh, 2011; Yu & Nagurney, 2013; Zamarripa, Aguirre, Méndez, & Espuña, 2012) explicitly modelling competition within the market. Among these papers, the demand is simultaneously modelled as a function of both the retailer's and the competitor's price (oligopolistic competition). These authors developed an equilibrium model to design a centralized SC network operating in markets under deterministic price-dependent demands and with a rival SC present. The competing chains provide products, either identical or highly substitutable, that compete for participating retailer markets. Using this approach, the authors were able to model the joint optimizing behaviour of these chains, derive the equilibrium conditions, and establish and solve the finite-dimensional variational inequality formulation. In six other models (Amaro & Barbosa-Póvoa, 2009; Cruz, 2009; Cruz & Zuzang, 2011; Meng, Huang, & Cheu, 2009; Yamada et al., 2011; Yang, Wang, & Li, 2009), demand is modelled as a function of only the retailer's price. Only one study modelled demand as a function of selected marketing policy (e.g., inventory-based replenishment policy, made-to-order policy or vendor managed inventory policy) (Carle, Martel, & Zufferey, 2012). None of the reviewed papers included customer service related factors—or, more specifically, the location or number of SC network points—in their demand models. However, the physical network structure of a SC clearly influences its performance and is an important factor that affects a chain's competitiveness, especially for retail markets.

SC risk management is also an important part of SC network configuration and optimization. SC risk management involves designing a robust SC network structure and managing the product flow throughout the configured network in a manner that enables the SC to predict and address disruptions (Baghalian, Rezapour, & Farahani, 2013). The uncertainties associated with disruptive events such as heavy rain, excessive wind, accidents, strikes and fires may dramatically interrupt normal operations in SCs. Hendricks and Singhal (2005) quantified the negative effect of SC disruptions on long-term financial performance (e.g., profitability, operating income, sales, assets and inventories).

In the literature survey, nine models (Baghalian et al., 2013; Bassett & Gardner, 2010; Cruz, 2009, Cruz & Zuzang, 2011; Kumar & Tiwari, 2013; Lundin, 2012; Masoumi et al., 2012; Pan & Nagi, 2010; Yu & Nagurney, 2013) explicitly included SC risk modelling (defined as SC robustness or SC risk models). In those models, the robustness of the models is quantified in SC risk equations to identify how it changes through the changes in the SC network.

A careful analysis of the SC network modelling literature finds that almost all SC network models assume that customer demands (either deterministic or stochastic) are not substantially influenced by the configuration of the SC network itself. However, the physical network structure of a SC clearly influences its performance and is one of the most important factors affecting a SC's competitiveness, especially for SCs serving retail markets. This disconnect between models and reality represents a gap in the literature and an opportunity for future research.

In this paper, the main objective is the integration of competitive facility location factors (e.g., changing demands dependent not only on price but also on customer service related functions) into SC network optimization model. As SC networks are multi-objective in nature, we define our model as multi-objective. Such multiple objectives might include profit maximization, sales maximization and SC risk minimization. Cost minimization and profit maximization are traditional objectives in SC network optimization problems. Sales maximization may also be utilized within the competitive facility location modelling framework as companies aim to increase (or at least maintain) their sales by reconfiguration of their SC network and possibly by adding new SC network point(s) (Plastria, 2001). The third objective proposed in the multi-objective framework is a risk minimization function. As SC risks have significant effects on the long- and short-term operational and financial performance of the SC (Hendricks & Singhal, 2005), strategic-level SC network decisions should be modelled with a risk metric to help understand how network decisions influence SC risks.

The principal contribution of the proposed model is the improved modelling of demands, which are affected by the price and service characteristics of SCs. The price and service, in turn, are substantially influenced by strategic-level SC network model decisions. As a second contribution of the proposed framework, SC risk will be included in modelling strategic-level SC decisions. Among the many published multi-objective SC network optimization models, only a few include SC risks as an objective.

3. Model definition

In this research, the model is built as deterministic Mixed Integer Linear Programming (MILP) with three echelon SC networks, with multiple products and a single period. The objectives of the model are to optimize SC configuration and to analyse how the location and number of DCs will influence SC performance metrics. The demand at each customer zone is assumed to be determined by the price and the utility function defined as DC-one day trans-