Computers & Industrial Engineering 57 (2009) 3–13

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

e-Work based collaborative optimization approach for strategic logistic network design problem

Pablo A. Miranda [a], Rodrigo A. Garrido [b], José A. Ceroni [c,*]

[a] Network Configuration Research Group and School of Industrial Engineering, Pontificia Universidad Católica de Valparaíso, Av. Brasil 2241 – Casilla 4059, Valparaíso, Chile
[b] Department of Transport Engineering, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Macul, Casilla 306, Santiago 22, Código 105, Santiago, Chile
[c] Collaborative Systems Research Group and School of Industrial Engineering, Pontificia Universidad Católica de Valparaíso, Av. Brasil 2241 – Casilla 4059, Valparaíso, Chile

ARTICLE INFO

Article history:
Available online 31 December 2008

Keywords:
e-Work
Collaborative optimization
Logistic distribution network design
Inventory location problem
Fleet design
Customer clustering

ABSTRACT

We propose a collaborative e-Work based optimization approach for assisting the strategic logistic network design problem, which considers fleet design and customer clustering decisions. Normally, fleet design and customer clustering decisions are made by mid-level logistics managers while network design decision is made independently by high-level logistics managers. In the proposed approach, strategic distribution network design is modeled as a Facility Location Problem, considering long term inventory control decisions. On the other hand, tactical fleet design and customer clustering decisions are modeled based on a Hub and Spoke cost structure. An e-Work based heuristic approach is proposed to solve collaboratively the network design problem at strategic and tactical levels. The collaborative solution approach results from a particular sequential decomposition of the problem, similarly to traditional location–allocation heuristics, modeling an information sharing strategy between decision makers involved at each organizational level. A numerical application of the approach with real data based instances shows significant benefits, when compared to a non-collaborative independent optimization, where the hierarchical levels share no dynamic information and base their decisions on static and independent optimization models. These results show evidence of the advantage of the e-collaborative approach to deal with logistic decisions at different hierarchical levels, organizational units, or companies, compared to non-integrated non-linear mixed integer programming models.

1. Introduction

Supply chain management (SCM) usually deals with problems of different nature and at hierarchical levels as discussed in Coyle, Bardi, Langley (1992), Miranda (2004), Miranda and Garrido (2004a), Garrido (2001), Mourits and Evers (1995) and Simchi-Levi, Kaminsky, and Simchi-Levi (2003), Chopra and Meindl (2003), Davies and Spekman (2003), Bradley and Arntzen (1999) and other related literature. Traditionally and contrary to the approach proposed in this research, each problem in SCM has been tackled by different organizational units within the same or among companies, based on independent and local methodologies. This sub-optimality of any independent approach shows the necessity for developing collaborative e-Work based methods.

In terms of supply chain efficiency, the network's ability to respond quickly and effectively to customers requirements is a key factor differentiating competing companies nowadays. Technological advancements through e-Work facilitate the way for meeting customer needs. Agility, quality, traceability, and service-ability depend on collaborative logistic networks that can focus on enhancing their performance by cooperative processes. Collaborative logistic networks are collections of supply chain partners designing and providing high quality and customized products (Chen, Chen, & Zhang, 1999). The general scope of e-Work was defined at the PRISM Center (Nof, 2000a, 2000b, 2003; Nof & Huang, 1998) as "any collaborative, computer-supported and communication-enabled productive activities in highly distributed organizations of humans and/or robots or autonomous systems", as it can be found in nowadays supply networks. These collaboration process and modeling within e-Work have been defined as e-collaboration. Under the overload of tasks and information, collaboration must be enabled, and as much as possible optimized, among people, machines and computers. Without effective e-collaboration, the potential of emerging and promising electronic work activities, e-Work, cannot be fully materialized (Nof, 2003).

The four main circles of knowledge in e-Work related literature are: "e-Work", "Integration Coordination and Collaboration", "Distributed Decision Support" and "Active Middleware" (Nof, 2003). In the "Distributed Decision Support" circle, research is focused on interaction-based decision making models with distributed

* Corresponding author. Tel.: +56 32 273708; fax: +56 32 273806.
E-mail addresses: pablo.miranda@ucv.cl (P.A. Miranda), rgarrido@ing.puc.cl (R.A. Garrido), jceroni@ucv.cl (J.A. Ceroni).

0360-8352/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cie.2008.12.007

knowledge sources, and human interaction, which would allow the decision structures to be adaptive and more responsive. Additionally, information exchange is required to influence other parties' local decisions, to act coherently and to achieve better results for the entire system. In this context, the proposed methodology is focused on providing a modeling and solving framework to address the problem of logistic network design, based on a Distributed Decision Support approach, in which different agents or decision makers e-collaborate each other in order to reach a better system solution. Section 1.1 presents a literature review of traditional approaches for addressing logistic network design, while Section 1.2 presents the collaborative e-Work basis for developing the proposed approach.

1.1. Traditional approaches in strategic logistic network design

Logistic network design is one of the most studied problems in SCM. Research literature includes numerous reports addressing diverse aspects of the general problem, considering a range of interaction degrees between strategic and tactical decisions. At strategic level, two of the most common approaches are the continuous approximation (Daganzo, 1996, 2004; Novaes, Souza de Cursi, & Graciolli, 2000) and facility location modeling structure. For a thorough review of Facility Location Problems (FLP), see Daskin (1995), Hamacher and Drezner (2002) and Simchi-Levi, Bramel, and Chen (2005). Traditional FLP consider deterministic parameters, demands, constraints, and objective function in a mixed integer modeling structure. However, based on the traditional FLP framework, it is hard to model interactions with other tactical decision issues of SCM, such as inventory control and fleet design problems. These potential interactions are shown in Fig. 1, where inventory control and vehicle routing decisions (at tactical and operational levels) interact with the strategic logistic network design problem.

Interaction between inventory control and facility location decisions has been considered in recent research literature. For example, Jayaraman (1998) incorporates the EOQ model's inventory and ordering costs into a FLP structure, assuming fixed lot sizes and deterministic demand. Nozick and Turnquist (1998, 2001) incorporate inventory costs assuming demand orders arrive in a Poisson process and a base stock inventory policy (consisting in a one-by-one ordering system). Nozick and Turnquist (1998) approximate a linear function of total inventory cost, within their FLP model, as function of installed distribution centers. Nozick and Turnquist (2001) minimize inventory cost and unfulfilled demand, incorporating them iteratively into the fixed installation cost. Daskin, Coullard, and Shen (2002), Miranda and Garrido (2004b) and Shen, Coullard, and Daskin (2003) present similar versions of a FLP model with inventory control decisions. In all these cases, the ordering decision is based on the EOQ model. A common factor among these models is the (Q, R) inventory control strategy, considering lot size as decision variable. The model structure assumes normality and independence in the demand behavior. The papers, however, differ greatly in their solution methods. Indeed, while Daskin et al. (2002) and Miranda and Garrido (2004b) apply different versions of LaGrange Relaxation, Shen et al. (2003) reformulate the problem as a Set Covering Problem, and then solve it through a hybrid heuristic mixing columns generation and branch and bound methods. In Daskin et al. (2002) and Shen et al. (2003) customers represent retailers, being any of them potential distribution centers. In Miranda and Garrido (2004b) customers could represent end consumers or aggregated demand. Miranda and Garrido (2004b) present a numerical evaluation of benefits of this simultaneous approach (inventory-location decisions), when compared to the independent optimization approach. Regarding system capacity, Ozsen, Daskin, and Coullard (2006) consider it as deterministic constraints of inventory capacity, while Miranda and Garrido (2006, 2008) modeled stochastic constraints of inventory capacity and order size capacity constraints in their inventory location models. Finally, Shen and Qi (2007) handle simultaneously inventory control and routing costs within a facility location model, considering nonlinear costs and stochastic demand. Their model is based on continuous approximation of routing costs for a multi-vehicle distribution system. However, the model does not consider the number of vehicles or routing zones as decision variables.

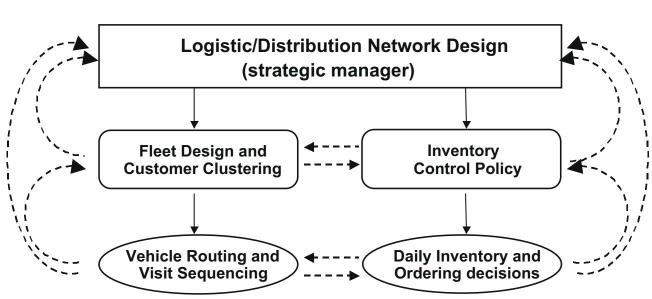

Fig. 1. Three hierarchical levels view of the distribution network design problem.

1.2. e-Collaborative logistic network design

Despite the simultaneous approach has the potential to yield optimal solutions of the logistic network design problem, its implementation results prohibitive in most cases. Model complexity is a key reason for this limitation (Miranda & Garrido, 2004c, 2006, 2008). Another reason lies on the requirement for large amounts of complex and hard to obtain data. A collaborative e-Work approach may prove useful in dealing with these complexities. In the case of manufacturing network design, a new modeling approach incorporating coordination communication cost is proposed in Ceroni and Nof (2005) and Ceroni, Nof, and Matsui (1999), which determines the profitability of the coordination based on net reward of the total system. Two alternative coordination modes are examined: (i) distributed coordination by two centers and (ii) centralized coordination by a third party. The results indicate that distributed and centralized coordination modes are comparable up to a certain limit; over this specific limit, distributed coordination is always preferred. In these researches, coordination cost is determined by evaluating communication overhead due to data transmission and transmission frequency over the optimization period. This method follows the concepts for integration of parallel servers developed by Ceroni et al. (1999). Communication overhead is evaluated based on the message passing protocol for transmitting data from a sender to one or more receptors (Lin & Prassana, 1995). The parameters of this model are exchange rate of messages from/to the communication channel, transmission start-up time, data packing/unpacking time from/to the channel, and the number of senders/receptors. Coordination of distributed sales and production centers has been modeled elsewhere in literature for investigating the benefits of different coordination modes. Results show that coordination cost and number of negotiation iterations should be considered in system's operational decisions. Coordination of distributed parties interacting for attaining a common goal is demonstrated significant also by Lin and Prassana (1995), with the inclusion of parallel servers in the system.

Considering these observations key in any collaborative process, and focusing on the strategic network design problem, the aim of our research is to develop a collaborative approach to solve strategic design of logistic distribution systems. The proposed approach is based on simultaneous modeling of facility location, inventory control, fleet design, and customers clustering, with a sequential collaborative e-Work solution approach.