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Strategic design and operational management optimization of a multi stage physical distribution system

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ABSTRACT

Design and management of logistic networks is one of the most critical issues in supply chain management. However, the literature does not contain any effective models, methods, and applications that simultaneously support management decisions in the strategic design of the distribution system, in the operational planning and organization of vehicles, and in container trips organization adopting different modes of transportation. The aim of this paper is to illustrate an original framework for the design and optimization of a multi echelon and multi level production/distribution system that combines mixed-integer linear programming modeling with cluster analysis, heuristic algorithms, and optimal transportation rules. A significant case study is illustrated revealing the effectiveness of the approach and tools proposed.

1. Introduction and literature review

Increasing global competition and cooperation have recently created the very critical logistical challenge of planning and coordinating the entire supply chain (SC). This involves minimizing global production costs while simultaneously optimizing the location of facilities, e.g. raw material sources, production plants, distribution centers (DCs), shops and branches etc., the allocation of customer demand to production/distribution centers as well as inbound and outbound transportation activities, the product and material flows between production and/or warehousing facilities, and reverse logistics activities.

All these problems are traditionally faced up and treated separately, but they have a common origin in the facility location (FL) problem. In logistic systems FL is defined by the taking of simultaneous decisions regarding design, management, and control of a generic production and distribution network. In the literature there are several studies that discuss FL, SC and logistic network optimization (Nozick and Turnquist, 2001; Chen and Paulraj, 2004; Manzini et al., 2006, 2008; Snyder, 2006; Agatz et al., 2008; Manzini and Gebennini, 2008; Manzini and Gamberini, 2008; Hammami et al., 2008; Thanh et al., 2008; Tsiakis and Papageorgiou, 2008; ReVelle et al., 2008; Zhang and Rushton, 2008; Wadhwa et al., 2008; Hinojosa et al., 2008; Baker, 2008; Chen and Ting, 2008). In particular, Melo et al. (2009) presents a recent review of the literature on FL and supply chain management. The large part of studies on FL and SC design an optimization focus on a single component of the overall system, e.g. procurement, production, transportation, or inventory management, etc. (Liang, 2008). Only a few studies propose useful operational models and methods enabling managers and practitioners to optimize SCs by focusing on the effectiveness of the whole system, i.e. by determining a global optimum.

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Arshinder et al. (2008) present a survey and classification of studies on SC coordination found in the literature. A critical review carried out by van der Vaart and van Donk (2008) measures the relationships between SC integration and performance. They found that a high level of integration has a positive impact on corporate and SC performance.

The most important decisions in FL are:

1. location of new supply facilities, e.g. a production plant or a distribution center, in a given set of demand points. The demand points correspond to existing customer locations;
2. demand flows to be allocated to new or available suppliers (i.e. production and/or distribution facilities); and
3. configuration of a transportation network i.e. design of paths from suppliers to customers, management of routes, trips, and vehicles in order to supply demand needs simultaneously.

An effective multi stage and multi-period approach integrating production, inventory, and transportation issues including vehicle loading and routing and related costs has not yet been presented by the literature studies. This manuscript presents and discusses an original and integrated approach to the problems of planning, designing, and executing the logistic activities in a multi level production and distribution system. This approach is also applied to a significant case study from the US tile industry. The main results are illustrated in the second part of the manuscript.

Usually treated and applied separately, three different levels of planning decisions (described in-depth by Manzini et al. (2008)) are integrated in the approach and models presented in this paper:

A. *Strategic planning*: This level refers to a long-term planning horizon (e.g. 3–5 years) and to the strategic problem of designing and configuring a generic multi-stage SC. Management decisions deal with the determination of the number of facilities, their geographical locations, the capacity of facilities, and the allocation of customer demand (Manzini et al., 2006).
B. *Tactical planning*: This level refers to both short and long-term planning horizons and deals with the determination of the best fulfillment policies and material flows in an SC, modeled as a multi-echelon inventory distribution system (Manzini et al., 2008).
C. *Operational planning*: The variable of time is introduced, correlating the determination of the number of logistic facilities, geographical locations, and capacity of facilities to the optimal daily allocation of customer demand to retailers, DCs, and/or production plants.

Several papers deal with the so-called joint location-routing problem (Balakrishnan et al., 1987) and others deal with the so-called joint inventory-routing problem (Kleywegt et al., 2002). The study in this paper differs from those in the literature because it combines the optimization of both production and distribution activities and pays particular attention to:

- strategic issues, e.g. facility location and determination of production/inventory capacity;
- tactical & operational issues, e.g. assignment of customers to the distributors available in a given period of time; and
- short-term shipment/transportation issues, e.g. the determination of the number of containers/vehicles and definition of the daily routing trips within geographical boundaries marked on maps and adopting a specific mode of transportation.

The proposed integrated cost based approach embraces facilities, production, warehousing, transportation, and routing management. It is based on the development of original mixed-integer linear programming (MILP) models and heuristic algorithms to find good solutions to some NP-hard problems which require managers and practitioners give up the idea of finding optimal solutions. MILP is widely used in FL, and in strategic planning in particular, as demonstrated by several studies in the literature (Manzini et al., 2008).

The authors also apply clustering modeling and techniques based on similarity coefficients to face up to the vehicle loading and routing issues. Consequently, the authors use a mix of models and tools to find solutions to problems traditionally solved separately.

The paper is organized as follows: Section 2 introduces the proposed approach to the design, management, and optimization of a distribution production system. It also illustrates three different and original mixed integer programming models for strategic planning. Section 3 presents methods and models for operational planning and organization based on mixed integer programming and clustering analysis. Section 4 introduces a case study in which the proposed approach, and its methods and models, is applied. Section 5 presents a detailed illustration of the results obtained by applying the strategic optimization to the case study. Similarly, Section 6 presents selected results obtained by applying clustering analysis and algorithms to support vehicle loading and routing in the case study. Finally, Section 7 presents conclusions and suggestions for further research.

2. Strategic design and operational management in a distribution network

Fig. 1 classifies the main issues and decisions regarding the design, planning, and scheduling of a logistic production and distribution system composed of multi level entities, e.g. sources, production plants, DCs, distributors, customers, etc.