Economic Modelling 37 (2014) 224–237

Contents lists available at ScienceDirect

Economic Modelling

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

An integrated multi-objective model for allocating the limited sources in a multiple multi-stage lean supply chain

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ARTICLE INFO

Article history:
Accepted 8 October 2013

Keywords:
Integrated supply chain
Inflation
Production programming
Inventory control
Lean methodology

ABSTRACT

In this paper, a multiple objective programming model has been presented as a supply chain with the general purpose of adopting an integrated approach such that with making optimal decisions about the optimum allocation of limited sources in the supply chain, selection of the suppliers, production, distribution and supply programming yields, the least cost and the most income and finally maximizes the profit of the chain. The proposed model attempts to regard the integration condition very well with consideration of factors such as the conditions for suppliers, producers, and distributors as well as free relations of producers with each other in the direction of providing products through a process or even the products from each other. The presented model, for more adaptation to reality, is flexible against the dynamism of the demand, and it considers the effect of economic factors on decisions such as inflation. A numerical example is then given to show the applicability of the proposed model. This model covers the operational dimension of the chain very well with appropriate programming for production and controlling the inventories.

1. Introduction

Supply-chain management, applying competitive strategies, integrates suppliers, producers, and distributors with the purpose of promoting responsiveness and flexibility within the organization vis-a-vis the customers. For this purpose, and in order to achieve the competitive benefits for more share of the market, the economic institutions shall manage and supervise the external sources and related elements within the organization as well as the organization itself and its internal source's consideration (Cohen et al., 2006; Garg et al., 2004).

The key problems in a supply chain are managing and control over the supply and demand program, selecting the suppliers, provision of raw materials, production and product programming, product storage, inventory control, distribution, delivery and customer services. Strategic programming of the supply chain results in the customers receiving reliable services, with high quality, fast and with the least-cost (Martin, 2006).

Mathematical programming models are one of the most applied methods for optimizing supply chains. The main purpose of these models is to make optimal decisions for allocating the limited sources in a long term considering various factors (Reiner, 2005; Yu et al., 2005). In general, the presented models for optimizing the activities of the supply chain have been designed in three types. The first type are the models whose objective is to study each part of the chain separately. For example, we can refer to the presented models for selecting the suppliers in a supply chain, the presented models for reducing delivery time in distribution centers, etc. The second type are the models only for reducing the costs, which create relations between both producers and distributors as well as distributors and customers. The third type are those qualitative models for the supply chain presented for either each part of the chain or a combination of the two parts in the chain (Reiner, 2005; Scott et al., 2003). In studying the models of the first and second type, we cannot declare deterministically that the decisions that are made are the most optimum feasible solutions, in that the co-relations between the nods and the sensitivity of affecting a part on another of the models are not a matter of consideration. In the study of the third type, due to non-quantitative decisions, we cannot also refer to them exactly for implementation, and they are only executive for the quality of the performed affairs. In most of these models, the model has become far from the world of reality regarding various hypotheses. However, we have attempted to adopt this model with the real conditions of one supply chain to the extent that it is possible (Ereng et al., 1999).

Considering the facts and the models just presented, the importance of an integrated model of the supply chain with all mentioned properties is clear (Wang et al., 2004).

Many researchers have made tremendous contributions to supply-chain management methods, but the majority of the published articles on supply chain models have focused on the single-period problem with a single objective function, rather than the entire supply chain network in several periods considering multi-objective models (Jang et al., 2002).

For instance, the production/distribution model (PILOT) of Cohen et al. (2006), is a cost function, mixed integer mathematical program with a nonlinear objective function. It is probably one of the earliest successful efforts to model supply chain problems. The authors presented a global supply strategy for manufacturing. This approach seeks to determine the number and locations of plants and distribution centers,

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http://dx.doi.org/10.1016/j.econmod.2013.10.018

material flows, plant production volumes, and the allocation of customers to distribution centers. Although this approach has generated a practical application model, it is limited to a single manufacturing stage and considers only one objective function based on supply chain costs. To overcome the limitations of considering only a single manufacturing stage, a number of researchers have considered the integrated production–distribution problem. Cohen and Lee develop a non-linear, stochastic, multi-echelon inventory model to determine the optimal stocking policy for a spare part stocking system, based on achieving an optimal trade-off between holding costs and transportation costs, subject to response time constraints (Cohen and Lee, 1987). This service system has unique characteristics, such as low demand rates, a complex echelon structure, and the existence of emergency shipments to meet unforeseen demand. The solution to this complex model is found using a branch and bound procedure. A mixed-integer programming developed by Robinson et al. considers a cost functional model for a two-echelon incapacitated distribution location problem. The authors provide sensitivity, cost–service tradeoffs, and what-if analyses to clarify all major costs and service trade-offs (Robinson et al., 1993). A fixed-charge network programming technique is used to determine the best shipment routings and shipment size through the distribution system. Vidal and Goetschackx in 1997 presented a critical extensive literature review of strategic production–distribution models. In (Vidal and Goetschackx, 1997), the authors categorize the literature into four groups: previous reviews, optimization models, additional issues for modeling, and case studies. A particular emphasis of their review is on mixed integer programming models. Thus, they identify the main characteristics of the mixed integer programming models, including the terms considered in the objective function, the constraints, and the specific characteristics of the solution methods and computation experiences. However, while there have been a considerable number of papers that consider the supply-chain problems, fewer studies have considered integration of the supply chain. For example, Tzafestas and Kapsiotis propose a mathematical program, with the objective of minimizing the cost of a sub-supplier/supplier/manufacturer in a supply chain (Tzafestas and Kapsiotis, 1994). Three different operational scenarios of optimizing the supply chain are assumed and examined. In the first one, manufacturing optimizes its operational costs without considering the suppliers. In the second scenario, overall cooperation exists between the three levels of the supply chain. In the last scenario, each level of the supply is optimized separately with a partial cooperation among the SC. A numerical example is provided to illustrate the above scenarios, and the simulation technique is used to verify the results. In this example, the differences in the total costs are very small, and the computational times are almost identical to the three scenarios.

To consider the integration of the supply chain, a number of researchers have studied the integrated supply chain problem.

Park (2007) presented a method for integrated production and distribution planning. He investigated the effectiveness of the integration through a computational study with the objective of maximizing the total net profit. It is considered one of the best production–distribution models in the literature, because it is a relatively realistic model considering multiple capacity constraints within a multi-period planning horizon. Moreover, the model involves some fixed costs at different operation stages. Having proposed an MIP (Mix Integer Programming) model, Park then presented alternative solutions and compared them in a computational study. In addition, a sensitivity analysis is carried out on capacities and fixed costs. However, this study assumed that the plants had an unlimited storage capacity, and that the firm could change the fleet size freely without extra cost, but in real operations, these assumptions are not often realized. Additionally, the model did not take changeover cost and production batch size constraints into account at the production stage. Moreover, the solution procedures have some limitations; for example, the decoupled models do not always give feasible solutions, since they ignore the interactions of different operation stages. Although the problem considered a supply-chain network configuration, including multi-plants, multi-retailers, multi-items, and multi-period environment, the key disadvantage is that no raw material procurement activities were considered (Park, 2007). Li et al. (2009) proposed a capacity allocation problem based on a more complex supply chain than has been typically considered in previous quantitative modeling studies. Hsieh and Liu examined a serial supply chain that consists of one supplier and one manufacturer. They investigated the supplier's and the manufacturer's quality investment and inspection strategies in four noncooperative games with different degrees of information revealed (Hsieh and Liu, 2010). Jula and Leachman (2011), propose a mixed integer non-linear programming model for optimizing the supply chains of importers of waterborne containerized goods from Asia to the USA and allocation programming. In their research, they introduce a heuristic algorithm to quickly solve the mathematical model to near optimality. Another problem in this area was configuration of supply chain and some researchers were focused on that. For example, Costantino et al. (2012), propose a model for configuration problem of Manufacturing Supply Chains (MSC) with reference to the supply planning issue. Their results show that the design method provides managers with key answers to issues related to the supply chain strategic configuration and agility, e.g., choosing the right location for distributors and retailers for enhanced MSC flexibility and performance. Another problem in the supply chain management is controlling the costs. Some researchers developed their model regarding to cost. As an example of this field, Pettersson and Segerstedt (2013), express a model to introduce a tool to measure the cost in the supply chain. They applied their model in 30 companies and show how does it works in the real world and they show the applicability of their model by this (Pettersson and Segerstedt, 2013). The remanufacturing process in supply chain management is another problem which some researchers like Giovanni and Zaccour in 2014 are concerned. They consider a two-period closed-loop supply chain (CLSC) game where a remanufacturer appropriates of the returns' residual value and decides whether to exclusively manage the end-of-use product collection or to outsource it to either a retailer or a third-service provider (Giovanni and Zaccour, 2014).

This study analyzes an integrated supply chain operation from raw material purchasing to final product distribution. The aim is to optimize the allocation of capacities among different facilities and product items. In this study, a mixed integer programming model with dynamic characteristics is presented first, and then alternative solution procedures are introduced. The solution procedures include the development of a decomposition heuristic and an integrated heuristic algorithm. A computational study compares the solution procedures and uses sensitivity analysis to show that the heuristics work well. Thus, through adequate modeling, the supply chain problem becomes more realistic sized.

In this paper, an integrated model for the supply chain is presented and an effort is made to define the objective functions so that the decision making in a supply chain is directed towards "lean". Finally, the results of the presented model make optimal decisions against the suppliers, producers, distributors and contractors, considering the relations between the producers such that any producer can supply for other producers.

Moreover, our model is sensitive to some factors such as inflation and the demand variable as well, and it reacts against change in each one of them. Lastly, we have made an effort to present a production programming and inventory control with consideration of its related costs. In general, the proposed model attempts to reduce costs, to increase incomes, and finally to increase the efficiency of the supply chain. In the following section, we propose our model. In Section 3, we illustrate the proposed model using a numerical example, and Section 4 concludes.

2. Proposed model

We assume that there are several suppliers who present their services for several producers who can supply for other producers or