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Lexicographic max–min approach for an integrated vendor-managed inventory problem

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ABSTRACT

Simultaneous reductions in inventory of raw materials, work-in-process, and finished items have recently become a major focus in supply chain management. Vendor-managed inventory is a well-known practice in supply chain collaborations, in which manufacturer manages inventory at the retailer and decides about the time and replenishment. In this paper, an integrated vendor-managed inventory model is presented for a two-level supply chain structured as a single capacitated manufacturer at the first level and multiple retailers at the second level. Manufacturer produces different products where demands are assumed decreasing functions of retail prices. In this chain, both the manufacturer and retailers contribute to determine their own decision variables in order to maximize their benefits. While previous research on this topic mainly included a single objective optimization model where the objective was either to minimize total supply chain costs or to maximize total supply chain benefits, in this research a fair profit contract is designed for the manufacturer and the retailers. The problem is first formulated into a bi-objective non-linear mathematical model and then the lexicographic max–min approach is utilized to obtain a fair non-dominated solution. Finally, different test problems are investigated in order to demonstrate the applicability of the proposed methodology and to evaluate the solution obtained.

1. Introduction

Vendor-managed inventory (VMI) is a well-known practice for supply chain collaboration, in which manufacturer manages inventory at the retailer and decides when and how much to replenish. In recent years, there has been an increasing interest in cooperative and non-cooperative relationship between both manufacturer and retailers in the VMI program. For instance, VMI has been adapted to the lean production requirements of manufacturers in automobile manufacturing supply chain management based on information system integration [14]. In order to analyze the supply chain performance improvement, Xu et al. [25] presented a real case study in a Chinese medium-sized aluminum manufacturing company. They showed the VMI strategy could significantly improve the supply chain performance such as reducing customer order cycle time and reducing safety inventory costs.

Although the benefits of VMI to the retailer include reduction of overhead costs and, if consignment stock is adopted, transfer of inventory costs to the manufacturer, the benefits of VMI to manufacturer are not very straightforward [11]. Meanwhile, research works mainly focus on the following three aspects of VMI programs [7]:

1. Investigating the benefits of VMI programs compared with normal supply modes without VMI.
2. Operational decisions in VMI programs.
3. Designing contracts for VMI programs.

The literature related to this paper can be classified into those of the second category.

Yao et al. [27] introduced a model to explore the effects of cooperative supply chain initiatives such as VMI, first developed by Vlist et al. [23]. In this issue, the authors showed that when the shipment sizes from a supplier to a buyer increase, inventory at the supplier goes down and inventory at the buyer goes up. Zhang et al. [33] presented an integrated VMI model for a single-vendor multiple-buyer supply chain problem, where the vendor first purchases and processes raw materials and then delivers

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finished items to multiple buyers. Investment decision, constant production, and demand were considered where the buyers' ordering cycles might be different and that each buyer could replenish more than once in one production cycle.

Impact of the consignment inventory (CI) and VMI policies was studied by Gümüş et al. [8]. The goal was to analyze CI in a two-party supply chain under deterministic demand and to provide some general conditions under which CI creates benefits for the vendor, for the customer, and for the two parties together. Sari [20] presented a comprehensive simulation model representing two popular supply chain initiatives, collaborative planning forecasting replenishment (CPFR) and VMI, in order to select an appropriate collaboration mode in business conditions. Their results showed that benefits of CPFR are always higher than VMI. Besides, an integrated production–inventory model was developed by Zavanella and Zanoni [32], in which a particular VMI policy known as consignment stock (CS) for both the buyer and the supplier was investigated. Yu et al. [29,30] showed how the vendor can take into account the advantage of his information for increasing his own profit by using a Stackelberg game in a VMI system. Yu et al. [28] showed how to analyze the intrinsic evolutionary mechanism of the VMI supply chains by applying the evolutionary game theories. Darwish and Odah [3] developed a model for a supply chain with single vendor and multiple retailers based on VMI, considering capacity constraints by selecting high penalty cost. Almehdawe and Mantin [1] studied supply chains composed of a single capacitated manufacturer and multiple retailers. They formulated a Stackelberg game VMI framework under two scenarios: in the first, the manufacturer is the leader; in the second, one of the retailers acts as the dominant player of the supply chain. In addition, market demand was considered a function of retail price. This model was also extended by Yu et al. [29,30] when advertising investment and pricing come to the picture.

The quaternary policy towards integrated logistics and inventory aspect of the supply chain was proposed by Arora et al. [2]. They considered a supply chain with multiple retailers and distributors, in which all distributors follow a unique policy and the VMI system is used for updating the inventory of the retailers. Yang et al. [26] studied the effects of the distribution centre (DC) in a VMI system comprising one manufacturer, one DC, and n retailers where the system aims to maximize the overall system profit. While Lee and Ren [11] showed the supply chain total cost decreases under VMI, the reduction is larger when there is exchange rate uncertainty compared with the case of no exchange rate uncertainty. They considered a state-dependent (s, S) policy for the supplier. Pasandideh et al. [18] presented a multi-product multi-constraint economic order quantity (EOQ) model under the VMI policy for a supply chain. They developed a genetic algorithm to find the best order quantities and the maximum backorder levels such that the total inventory cost of the supply chain is minimized.

A logistics network design under VMI by considering location, transportation, pricing, and warehouse–retailer inventory replenishment decisions was presented by Shu et al. [22]. Zanoni et al. [31] provided a two-level supply chain model for a single-vendor single-buyer at each level and compared different policies that the vendor might adopt to exploit the advantages offered by the VMI with consignment agreement when the vendor's production process is subject to learning effects.

To summarize, many research works in supply chain environment assume a non-cooperative relation (such as the one in the Stackelberg game) between the manufacturer and the retailers with the manufacturer acting as the leader and the retailers as the followers [1]. In addition, most of the literature on the VMI problem only aim to optimize manufacturer's objectives and do not pay attention to retailers' objectives [29,30,1]. Moreover, there has been little discussion about designing fair contracts in VMI problems so far. Besides, previous research works on this topic mainly included a single objective optimization model where the objective was either to minimize the total cost or to maximize the total benefit. However, this paper presents a two-level supply chain model by assuming a single capacitated manufacturer at the first level and multiple retailers at the second level. This chain is considered integration between the manufacturer and retailers where the manufacturer (vendor) produces multiple products, sells to retailers, and manages the retailers' inventories under VMI. A fair profit contract between the manufacturer and his retailers is adopted in this research. Our motivation of defining a fair profit contract is that both the manufacturer and retailers are able to contribute to determine their optimal decision variables in order to maximize their benefits. In other words, the manufacturer and his retailers maximize their benefits as close to one another as possible. Besides, the demand rate for each product in each local retail market is assumed a decreasing function of the retail price called the Cobb–Douglas demand function. Finally, this paper formulates the problem into a non-linear mathematical model with two-objectives in order to maximize both the manufacturer and retailers' benefit. It is assumed that both the objectives are equally important, and it is needed to find a "fair" non-dominated solution by the lexicographic max–min approach. A fair non-dominated solution is a solution with all normalized objective function values as equal as possible. Following Erkut et al. [6], we discuss the conversion of the original lexicographic max–min problem to a lexicographic maximization problem without using the dual formulation of the LP problem.

The reminder of this paper is organized as follows. Section 2 contains problem description. The mathematical formulation of the problem is given in Section 3. Section 4 discusses the lexicographic max–min approach to solve the problem. The applicability and the performances of the proposed method are demonstrated in Section 5 using some numerical examples. Moreover, sensitivity analyses on the effects of some input parameters on the objective functions are performed in this section. Finally, we conclude the paper with a discussion of possible further research in Section 6.

2. Problem description

Consider a two-level supply chain consisting of a single manufacturer at the first level and multiple retailers at the second. The manufacturer's capacity is finite in producing different products with a fixed production rate. He sells the products to its retailers with a common replenishment cycle. A common replenishment cycle eliminates the influence of the variation of the replenishment cycle as well as backorder rate of every retailer. The manufacturer must sell the products to his retailers at different wholesale prices. Besides, the manufacturer and retailers are operating in distinctive markets with no conflict of interests. Integration is established between the manufacturer and all retailers, in which manufacturer manages inventory at all levels by having access to retailers' inventory as well as his own (i.e. VMI). Moreover, each retailer pays to the manufacturer a cost of ξ_{ic} per unit consumed per time unit to have his inventory managed by the manufacturer. The manufacturer decides on his replenishment cycle of the finished products, wholesale prices, and fraction of backlogging. Retailers' decisions include their retail prices.

2.1. Assumptions

The followings are assumed in this paper:

1. The demand for every retailer and every product is constant over time.