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On the comparison of inventory replenishment policies with time-varying stochastic demand for the paper industry

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ABSTRACT

The aim of this paper is the development of a mathematical model to compute the optimal inventory mix to face stochastic demand at minimum cost in a two-level supply chain. The paper addresses a multi-product dynamic lot-sizing problem under stochastic demand subject to capacity and service level constraints. This model is executed to compare a Make To Order (MTO) strategy to a Vendor Managed Inventory (VMI) partnership between the supplier and their customers. Both strategies provide the demand order to be produced. A schedule of production orders is determined over the planning horizon in order to minimize the inventory holding costs of the supply chain, taking into consideration that the supplier is also responsible of initiating the replenishment orders and deliveries of their customers according to the VMI partnership. The simulation model is illustrated empirically using a real case study: a paper manufacturing company that pursues to improve customer service level and supply chain inventory costs through a proper production planning of their paper machines and a suitable VMI order replenishment schedule.

1. Introduction

Production lot-sizing has a great impact on inventory, particularly under seasonal fluctuations of demand and constrained production capacity. Many companies adopt the MTO (Make To Stock) policy in which products are not built until a confirmed order for products is received by the manufacturer. Other companies maintain high levels of inventory (stock) to face periods of uncertain demand. However, a production schedule which does not adjust accurately the real demand may lead to overstocks for some products and stock-outs for other. Inventory sizing by product is especially important under uncertainty, when the inventory is necessary to guarantee a service level in a stochastic environment. One of the integration practices that can contribute to reduce inventory in the supply chain is Vendor Managed Inventory (VMI). VMI programs allow for consumer demand information to be disseminated up the supply chain, thus mitigating upstream demand fluctuations due to the bullwhip effect [1,2]. Due to this demand anticipation, VMI may allow to reduce logistics and manufacturing costs, reduce overall lead-times, improve service level and reduce transportation costs.

The aim of this paper is the development of a mathematical model to seek the most effective inventory mix to face stochastic demand at minimum cost in a two-level supply chain. We focus on a multi-product dynamic lot-sizing problem under stochastic demand subject to capacity and service level constraints. Unlike previous studies, this model is executed to compare a MTO strategy to a VMI partnership between the supplier and their customers [3]. Both policies are developed

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within the model, and their results are compared within the numerical application. The work presents some forecasting nonlinear optimization models that can be brought from Applied Science as done in [4–6].

In the problem, a schedule of production orders is determined over the planning horizon in order to minimize the inventory holding costs of the supply chain, taking into consideration that the supplier is also responsible of initiating the replenishment orders and deliveries of their customers according to the VMI partnership. The model also considers features such as service level required, the production capacity at machine level, set up time or product–machine allocation. The integration of stochastic demand in the production/inventory model is performed through the statistical distribution of the forecast accuracy. Historical data are analyzed to select the most suitable forecasting model for each reference (also called SKU). The selected model is triggered to forecast the demand during the rolling horizon.

The applicability of the proposed model is illustrated empirically using a real case study: a paper manufacturing company that pursues to improve customer service level and supply chain inventory costs through a proper production planning of their paper machines and a suitable VMI order replenishment schedule. A cost analysis of the supply chain inventory under different service levels and under different adoption rates of VMI, in concordance with local convergence achieved (see [7]) by the simulation and optimization, demonstrates the potential of this model to improve performance in the supply chain.

The paper is organized as follows. In Section 2 we give an overview of previous work in replenishment policies and lot sizing problems. In Section 3, we describe the methodology applied to the paper industry by placing emphasis on the forecasting models which help to estimate the demand of the customers. The mathematical formulation is described in Section 4. Here we will see how the customers and manufactures variables are connected with the replenishment policies. The simulation algorithm is described in Section 5 as a loop where customers and manufacturers trigger orders to be manufactured when the control parameters reach certain values. In Section 6 the results obtained are analyzed and the discussion of the outcomes and conclusions are shown in Section 7.

2. Literature review

The work in [8] was one of the first papers that provided insights into the VMI approach by explaining the savings that so often accrue from this strategy. In addition, they describe some underlying technologies required to make the arrangement work.

In [1], the authors seek to find the supply chain that minimizes system cost through comparing performance between traditional and VMI systems. A mathematical model is developed, and total supply chain cost is used as the measure of comparison. The models are applied in both traditional and VMI supply chains based on pharmaceutical industry data, and we focus on total cost difference compared through the use of Adjusted Silver Meal (ASM) and Least Unit Cost heuristics.

The work in [9] aims at designing a dynamic VMI system in which the entire supply chain performance is optimized in terms of production planning at vendors site, distribution strategy, and inventory management at manufacturers site. The VMI system is modeled as a mixed-integer linear program (MILP) using discrete-time representation and the mathematical representation follows the resource-task net-work formulation. To address the complexity of the problem, the problem is solved directly using an exact detailed model, an iterative procedure combines a novel aggregate model with the detailed model and a novel rolling horizon approach that simultaneously combines the aggregate and the detailed models is designed to solve the problem.

In [2] is presented a fractal-based approach for inventory management. A fractal-based echelon does not indicate a functional level or composition of supply chain members but indicates a group of multi- or hetero-functional fractals. The basic fractal unit (BFU) consists of five functional modules including an observer, an analyzer, a resolver, an organizer, and a reporter. They develop mathematical models for the analyzer and resolver to effectively manage supply chain inventories.

The paper [10] compares three replenishment strategies in a two-echelon serial supply chain. These strategies include Make-to-Order, Make-to-Stock, and Vendor Managed Inventory. To compare these strategies, they develop several probability models that we use to calculate the expected fill rate, average customer inventory, and average manufacturer inventory. The second study determines the benefit of VMI in a two-echelon arborescent supply chain.[11] compares the expected performance of a VMI supply chain with a traditional *serially-linked* supply chain. The emphasis of this investigation is the impact these two alternative structures have on the *Bullwhip Effect* generated in the supply chain. They pay particular attention to the manufacturers production ordering activities via a simulation model based on difference equations.

3. Methodology for the paper industry problem

The case study addressed in this paper is related with the supply chain for the pulp and paper industry. The sector comprises companies that use wood as raw material and produce pulp, paper, board and other cellulose-based products. This work is focused in the two-echelon operations from the manufacturers (facilities that processes the raw material) and the customers that receives the paper and produces strong, lightweight cardboard boxes. The manufacturers must meet the customer's requirements in terms of paper quality, wide and other paper properties. Several approaches are launched to schedule the production into the paper machines. Board must be dispatched to the customers by different transport modes as in [12].