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Vendor managed inventory (VMI) with consignment considering learning and forgetting effects

Simone Zanoni [a,*], Mohamad Y. Jaber [b], Lucio E. Zavanella [a]

[a] *Department of Mechanical and Industrial Engineering, Università degli Studi di Brescia, via Branze 38 25123 Brescia, Italy*
[b] *Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, Ontario, Canada M5B 2K3*

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ABSTRACT

The paper considers two research issues that usually interact in practice, which are the 'VMI with consignment' inventory policy and the 'Learning Curve'. Under a VMI with consignment agreement, the vendor is the one who manages the buyer's inventory, and he holds the property of the inventory until the withdrawal of the buyer: this practice also offers to the vendor the possibility of revising its production plans and shipments according to alternative policy also exploiting the opportunity offered by learning in production. The paper, which considers a two-level supply chain system with a single-vendor and a single-buyer at each level, investigates and compares different policies that the vendor may adopt to exploit the advantages offered by the VMI with consignment agreement when the vendor's production process is subject to learning effects. The main result of the study is to show how learning in production can give flexibility to the supply chain stake holders in assigning the size and the time of each shipment.

1. Introduction

This study is concerned with a special inventory management practice in supply chains known as VMI with consignment according to the classification of inventory systems proposed by Lee and Whang, 2008. Although consignment stock policy has been noted in the literature some time ago, an analytical model for the VMI with consignment policy was first proposed by Braglia and Zavanella (2003). The application of this policy (in practice) over different industrial sectors increased considerably in the past few years, confirming its economic benefits.

In manufacturing environments, the ideal candidates for starting the implementation of a VMI with consignment policy are those firms whose items already provisioned according to an "open order" scheme. These codes (items) are generally inexpensive (e.g., nuts, screws, some raw materials) and their stock levels are frequently assessed by the vendor (Valentini and Zavanella, 2003). However, recently, the VMI with consignment business practice has been applied to manage the inventories of critical and strategic items that are usually associated with high financial costs (e.g., an interesting application may be found in spare part management of complex oil refineries, as in Zanoni et al. (2005)). In such a case, the vendor (producer of service parts) benefits by exploiting the economies of scale through larger batch sizes (where additionally the learning effects in production may be exploited), while the buyer (oil refiner) benefits by experiencing an higher service level of spare parts for his plant. Moreover, the vendor may also benefit from the situation when multi-buyers are considered (Zavanella and Zanoni, 2009). Furthermore, several VMIs with consignment applications involve items that are co-designed and/or produced under a co-makership agreement, thanks to the natural development of partnerships for manufacturing and provisioning complex and critical parts (e.g., frame and chassis in the automotive field, groups of preassembled codes for valves or appliances production). Such a partnership is very relevant when satisfying the demand for newly launched products, a period during which learning benefits are particularly perceived and observed by the vendor. Strong relationship of the VMI with consignment agreement usually establishes between the partners (e.g., vendor – buyer) evolves naturally from inexpensive codes to including critical and expensive ones. In the authors' opinion, these considerations show how the present study may contribute to practice and to the understanding of the managerial implications when VMI with consignment policy is implemented as a partnership/coordination mechanism in firms. In particular, the VMI with consignment policy developed here is analysed in a setting where the vendor experiences learning in production.

The effects of learning in different industrial settings have been investigated in several studies, e.g., lot sizing (Jaber and Bonney, 1999), dual resource constrained systems (Jaber et al., 2003), quality (Jaber and Guiffrida, 2004), supplier quality (Jaber et al., 2008), and supply chain coordination (Jaber et al., 2010). Although learning improves systems productivity and reduces its cost, it may be impeded by its opposite phenomenon-forgetting.

* Corresponding author. Tel.: +39 030 3715474; fax: +39 030 3702448.
E-mail addresses: zanoni@ing.unibs.it (S. Zanoni), mjaber@ryerson.ca (M.Y. Jaber), zavanell@ing.unibs.it (L.E. Zavanella).

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Forgetting has usually been associated with production breaks during which the facility is idle, producing (performing) different products (activities), or due to labour turnover. These breaks result in some of the knowledge acquired (usually measured in units) to be lost; so relearning is experienced when the same production activities resume, which is costly to firms. The longer the break, the more costly the forgetting; so a production manager has to find the right trade-off between the different costs, including learning and relearning.

The effects of learning and forgetting on the lot sizing problem were first investigated by Keachie and Fontana (1966), with a reasonably comprehensive review of the literature (1966–2011) appearing in Jaber and Bonney (2011). Recent studies on the topic are found in Jaber and Guiffrida (2007), Jaber and Bonney (2007), and Jaber et al. (2009). Although the applications of learning and forgetting to inventory problems have been of interest and relevance, very few researchers have investigated them in the context of a supply chain coordination. The first reported work is that of Nanda and Nam (1992), which investigates a joint replenishment policy in a two-level (manufacturer-retailer) supply chain with a single buyer, further extended to a multiple buyer case (Nanda and Nam, 1993). In these works, they considered lot-for-lot (LFL) policy and a quantity discount schedule. Forgetting effects were considered as a percentage of accumulated experience. Jaber et al. (2010) investigated a three-level supply chain (supplier – manufacturer – retailer) where the manufacturing operations undergo a learning-based continuous improvement process by encountering learning and forgetting effects in setups, production, and product quality. These articles demonstrate the paucity of the research that investigates learning and forgetting effects on joint replenishment policies in supply chains. Investigating learning and forgetting in a supply chain that adopts VMI with consignment as a business practice will make an original contribution to the literature, which this paper provides.

The paper is organised as follows. Section 2 provides a brief description of the learning and forgetting process. The problem description and the notations used are presented in Section 3. Section 4 describes the model structure, hypotheses, and features for the different inventory strategies that have been identified. Section 5 provides numerical examples, and discussion of results where some managerial insights are drawn. Finally, in Section 6, some concluding remarks are presented and future extensions are outlined.

2. Problem definition and notation

An integrated inventory model (IIM) for the case of a single-vendor (e.g., manufacturer) and a single-buyer (e.g., retailer) was first proposed in Goyal (1976). The VMI with consignment practice can be viewed as a special case of IIM. This practice operates in a manner where the vendor ships items of a product in batches to the buyer's warehouse, which is managed by the vendor too. The vendor guarantees that inventory for items is always available and no stock-out occurs. The rationale for shifting the inventory to the buyer's end is cost related as the storage cost is incurred by the buyer and not by the vendor. The buyer pays for items upon their withdrawal from its warehouse. Thus, the vendor's and the buyer's holding costs are reduced as the vendor incurs no storage cost while the buyer does not need to invest in inventory.

The problem described here assumes constant demand at the buyer's end; the orders are shipped instantaneously to the buyer by the vendor with no lead time, no shortages are allowed and all items produced and received by the buyer conform to quality requirements. Moreover it should be noted that Braglia and Zavanella (2003) preliminary showed how VMI with consignment may also improve the performance of an inventory system in stochastic environments: an analytical model for the VMI with consignment considering stochastic demand can be found in Tang et al. (2007).

At any time, the vendor's manufacturing facility is either idle (production break) or producing a given product at a constant rate. It is also assumed that the vendor's and the buyer's setup and order costs are, respectively, fixed and independent of the order/production quantities. Both parties' inventory costs are also assumed to be directly proportional to their average stock levels. The performance criterion used in the study is the sum of the inventory holding and ordering costs.

The learning model considered here assumes that learning is a natural phenomenon (learning-by-doing) and it requires no investment as a result. It is also assumed that the transfer of learning between production cycles can take one of the following forms: (1) full (i.e., no forgetting), (2) partial (some of the knowledge is lost due to forgetting), and (3) total forgetting. The learning – forgetting relationship is assumed to follow the learn – forget curve model (LFCM) developed by Jaber and Bonney (1996) whose mathematics are provided in Section 2. The LFCM was shown to have a strong theoretically foundation (Jaber and Bonney, 1996, 1997; Jaber et al., 2003; Jaber and Sikström, 2004a) and fitted empirical data well (Jaber and Sikström, 2004b).

Finally, it should be emphasised that, in comparison with the most recent literature on VMI with consignment (e.g. Zavanella and Zanoni, 2009), the labour cost will be explicitly introduced as a fundamental component of the production cost. In fact, learning effects are particularly evident in manned environments, where experience impacts production efficiency and, consequently, the time to satisfy demand. In our opinion, this aspect introduces additional interest to the study proposed.

2.1. Notations

2.1.1. Input parameters

D	demand rate per unit of time
P	vendor production rate (for feasibility, it is assumed that $P \geq D$)
A_1	order cost for the vendor (i.e. set-up cost for the production)
A_2	order cost for the buyer (i.e. ordering cost for each shipment)
h_r	holding cost per unit of time at the buyer excluding the financial component (i.e. the holding cost borne by the buyer in a VMI with consignment agreement)
$h_{v,1}$	holding cost per unit of time at the vendor's side, including the financial and non-financial holding cost components
$h_{v,2}$	vendor's holding cost at the buyer's facility without the non-financial components (i.e. the holding cost borne by the vendor in a VMI with consignment agreement, when items are in the buyer's warehouse)
c_ℓ	the labour cost per unit of time
T_1	time to process the first unit (that is equal to $1/P$)
b	learning exponent in production
u_i	cumulative experience of equivalent units of experience at the beginning of cycle i.

2.1.2. Decision variables

q	size (number of items) of the batch shipped from the vendor to the buyer
n	number of shipments in a cycle