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# Vendor Managed Inventory (VMI) with Consignment Stock (CS) agreement for a two-level supply chain with an imperfect production process with/without restoration interruptions

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## ABSTRACT

A vendor managed system with the Consignment Stock agreement is a business practice where a buyer's inventory remains the property of the vendor until its withdrawal by the final customer demand. Such an agreement has shown to be a profitable stock management approach, especially when operating in uncertain environments where delivery lead times and/or market demand vary over time.

One main issue that has been addressed in the literature on supply chain coordination is when a vendor's production process is imperfect; i.e., it generates defective items that are either reworked or scrapped. From the available works that investigated coordinating orders between a vendor and a buyer with imperfect production, to the authors' knowledge, no one has considered a Vendor Managed Inventory (VMI) with the Consignment Stock (CS) agreement as a policy where the vendor's production process is imperfect. This paper also introduces various managerial decisions pertaining to imperfect items, specifically, reworking items and applying minor-setups for restoration. A mathematical model is developed to determine the optimal production-inventory policies for various possible scenarios. The managerial decisions incorporated in this model give it the flexibility required to adapt to a firm's production situations and needs as may arise due to the nature of different industries and businesses.

Significant findings include that accounting for imperfect items with Consignment Stock practice increases the batch size, reduces the number of batch shipments per cycle, and reduces the overall cycle time. Further, introducing minor setups for restoration reduces the overall cost of the system.

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## 1. Introduction

Inventory systems have various supply chain coordination policies (Jaber and Zolfaghari, 2008). Vendor Managed Inventory (VMI) with Consignment Stock (CS) agreement is one of these policies that has been observed in the automotive industry (Valentini and Zanarella, 2003) and studied by researchers (Braglia and Zanarella, 2003). This study introduces VMI with the Consignment Stock agreement as well as the consideration of an imperfect production process in a supply chain context.

Inventory consignment is a business arrangement where a 'buyer' holds items in its inventory without 'owning' them (Simchi-Levi et al., 2000). The buyer makes appropriate payments for the purchase of consumed items. That is, within the CS inventory model the

'change of ownership' of the items is unrelated to the shipment of the items from one party (the vendor) to the other (the buyer). This is contrary to the basic design of classical inventory systems (e.g., Jaber and Zolfaghari, 2008; Glock, 2012).

Braglia and Zanarella (2003) considered a single-vendor and a single-buyer scenario to help in understanding the behavior and aptitude of the Consignment Stock policy in the supply chain coordination context. Although the concept of VMI with CS agreement is not new, it is the work of Valentini and Zanarella (2003) that provided an initial foundation for most of the later work regarding this policy. The mathematical model of Braglia and Zanarella (2003) is considered the base-case model, which this study builds and extends upon. Furthermore, Braglia and Zanarella (2003) provided a comparison with the classical model of Hill (1997, 1999) and concluded with a proposal for identifying situations in which the CS policy's implementation could be advantageous. They also concluded that the CS policy might be a strategic and profitable approach for supply chain coordination when

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delivery lead times or market demands vary with respect to time. Zaroni and Grubbström (2004) developed an explicit form of the implicit analytical solution given in Braglia and Zanavella (2003), while Persona et al. (2005) proposed an analytical model to take into account the effects of obsolescence. Wallin et al. (2006) identified and explained the critical factors that steer a firm's decision when making choices regarding inventory speculation, inventory postponement, inventory consignment and reverse inventory consignment. Srinivas and Rao (2007) developed four stochastic versions of the CS model which are (1) a basic CS model, (2) CS with delays, (3) CS with information sharing and delays, and (4) CS with controllable lead-time. Battini et al. (2010) extended the work of Persona et al. (2005) by considering demand variability, stock-out risk and limited warehouse space for low unit cost, high demand and small size (easy to store) items. To the authors' knowledge, there is no available work in the literature that explores a two-level supply chain operating under a CS agreement for the case when the vendor's production process is imperfect with defective items generated and where different alternative scenarios for managing scrap and/or rework are considered.

VMI and CS are commonly misperceived as the same; however, the underlying difference is that in the VMI the replenishment of orders at the buyer's side is generated by the vendor (Holweg et al., 2005). VMI systems in general are perceived to have substantial success in inventory studies (Sari, 2007; Claassen et al., 2008), but further investigations showed that adopting a VMI policy or a CS agreement is profitable (Chen et al., 2010) and demonstrated that there are benefits from combining the two (Gümüş et al., 2008). Sui et al. (2010) also showed success from the implementation of a VMI system with a consignment inventory. Their simulation-based approach allowed them to relax simplifying assumptions more common with analytical modeling of similar systems. Other advantages that can be gained from a VMI model with CS agreement are discussed in Zaroni et al. (2012). They compared different policies that the vendor may adopt when the vendor's production process is subject to learning effects.

The assumptions that the equipment and machinery used in a production process are not subject to failures and that the output produced from the process has no defects are not realistic (e.g., Agnihotri and Kenett, 1995; Khan et al., 2011). Porteus (1985, 1986) and Rosenblatt and Lee (1986) were the first to independently modify the economic order/production quantity (EOQ/EPQ) model by assuming that a production process, which starts in a control state, may shift with a specified probability to an out-of-control state. They also assumed that the process remains in that state until the entire lot is produced. Their work has provided a foundation for some inventory and supply chain models (e.g., Urban, 1998; Khouja, 2003; Jaber and Zolfaghari, 2008; Khan et al., 2011). One of the interesting works that stemmed from that line of research is the one that considers interruptions to restore the production process into an in-control state at a cost (minor setups). Khouja (2005) extended the work of Porteus (1986) by assuming that a production process can be interrupted and restored. The more frequent the interruptions the less the number of defects generated, but the cost of restoration is higher. The policy is to determine the optimal number of interruptions in a cycle and the lot size that minimize the total system cost. The model of Khouja (2005) was later investigated in a two-level (vendor-buyer) supply chain with reworks (El Saadany and Jaber, 2008).

The concept of imperfect production with process restoration has not been investigated in a VMI with CS agreement context. The advantages of VMI with CS agreement are prevalent for specific considerations. Many suppliers are attracted to the VMI policy because it mitigates uncertainty of demand and that items are readily available to the buyer when needed (Piplani, 2006).

Organizations should always ensure smooth and efficient running of their operations (Hayek and Salameh, 2001), and having imperfect items in the system will counteract these advantages. Moreover, VMI material is stored at the buyer's warehouse, which is usually associated with lower holding costs. Shipping imperfect items to the buyer to have them scrapped or then returned to the vendor for rework may not seem to be economical and may counteract the benefits of applying VMI with CS agreement. The popularity of VMI has been seen from the 1980s through their introduction in Walmart and Procter & Gamble, and later initiatives by other companies including Campbell Soup, Johnson & Johnson and by European firms as well (Waller et al., 1999). The application of VMI and the concerns aforementioned are considered motivations to perform this study. Furthermore, there is no work in the literature that investigates imperfect production in a two-level supply chain with CS policy (Jaber and Zolfaghari, 2008; Glock, 2012), which makes this paper the first.

Hereafter, the paper is organized as follows. Section 2 presents the mathematical model developed. Section 3 tests the model using numerical examples and discusses the results. The paper is summarized and concluded in Section 4 with insights into future work.

## 2. Mathematical model

### 2.1. Problem definition

The main goal of this study is to further explore the modeling of VMI with consignment agreement as presented by Braglia and Zanavella (2003) by accounting for rework of imperfect items and the application of interruptions to perform minor setups to restore the production process. This will allow the developed model to be a step closer to representing a real-world situation. It will also open further managerial decisions to be made and will provide a more thorough understanding of the nature of the CS policy. Specifically, this paper develops a supply chain model that considers the problem of a single-vendor and a single-buyer and portrays the CS policy subject to:

- (i) a vendor's imperfect production process that generates defective items that are either scrapped or reworked;
- (ii) different scenarios to manage the scrap and rework items at the vendor's side, as necessary interventions to meet the final demand; and
- (iii) interruption of the production process for the purpose of restoring its quality at a cost (minor setups).

### 2.2. Model concept and construction

#### 2.2.1. Scope of the model

The fundamental concept of VMI with CS agreement is that the inventory is located at the buyer yet managed by the vendor (manufacturer). Moreover, if the CS agreement is considered, 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. In essence, the vendor is seeking to utilize the buyer's warehouse to stock material. Consequently, it is assumed that the vendor will only deliver conforming items to the buyer's warehouse.

Considering imperfect production, there is a probability the production process at the manufacturer goes 'out-of-control' and hence produces items that do not conform to the specified

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