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A joint economic lot size model with third-party processing

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ABSTRACT

This contribution presents a production-inventory model for a supply chain that incorporates three distinct entities a Vendor, a third-party external Manufacturer and a Buyer. The Vendor purchases raw materials from a supplier and performs preliminary manufacturing operations, the semi-finished goods are sent to a third-party Manufacturer for additional manufacturing operations then the products are sent back to the Vendor for final operations or assembly with other components and finally they can be sold to the customer. The study of this particular Supply Chain configuration has been inspired by an industrial case observed in the aeronautical sector.

The aim of this work is to analyse the performance of different supply chain configurations with third-party processing for operations carried out by the Manufacturer. The first option is to consider a traditional production-inventory system where the Vendor and the Manufacturer follow a centralised traditional agreement policy. The second option involves a centralised Vendor Managed Inventory policy with consignment stock agreement between the Vendor and the Manufacturer. The objective is to determine the optimal lot size policy, i.e. traditional agreement or consignment stock agreement, in order to minimize supply chain total cost.

Finished goods are assumed to have price-independent deterministic demand, while cost components are assumed to be constant over time. The analysis is carried out considering system total cost as the objective function to be minimized.

1. Introduction

In order to create and maintain competitive advantages in today's business environment, a high level of coordination is required in supply chains. To assist decision makers in operations decisions in supply chains, the concept of joint economic lot size (JELS) model has been introduced, which refines traditional methods for independent inventory control. The purpose of JELS models is to find a more profitable joint production and inventory policy, as compared to the policy resulting from independent decision making.

Third-party processing with external manufacturers is very common in several highly specialized sectors, such as aircraft or automotive parts manufacturing. In general, the main reasons for third-party processing with external manufacturers can be summarized as follows:

(1) reduce and control operating costs;
(2) improve company focus;
(3) gain access to world-class capabilities;
(4) free internal resources for other purposes;
(5) access to resources that are not internally available (financial and/or technological and/or environmental restrictions).

The industrial practice that inspired the development of the present contribution is related to a highly specialized company operating in the aerospace industry. Typically, the supply chain of the aerospace industry includes the final product (e.g. helicopters/aircrafts) manufacturer that is mainly active in the engineering phase of the product development and in the final assembly, often due to product complexity, that usually require high tech operations, the manufacturer orders product parts to specialized companies (i.e. first tier suppliers). Moreover, these companies purchase sub-parts or pay for external production phases to their respective sub-suppliers (named second tier suppliers or external Manufacturer). In particular, it's very common that some phases of the production cycle of the first tier supplier (e.g. highly specialized chemical treatment), are completed by an external Manufacturer. So, in many cases, the part firstly processed by the first tier supplier, it is then shipped out to the external Manufacturer for the chemical treatment and after its completion, it is sent back to the first tier supplier for the final processing phases.

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This particular arrangement of Supply Chain requires at a first look an unnecessary shipment back to the vendor which certainly adds to the supply chain cost, increasing also the entire Supply Chain lead-time. However, such kind of configuration, even if add operational complexity (the coordination activity required to the vendor for managing the forward and backward flow with the external manufacturer) in several industrial cases observed is forced by the specific technology and knowledge on some intermediate operations required for the finalisation of the product produced by the vendor and ordered by the buyer. Some of that intermediate operations can also require specific certification of the process particularly restrictive in specific sectors such as aeronautical or automotive, that imply a specific technology and process knowledge that can be concentrated in few manufacturers over the world. Moreover, the annual volume of these particular operations may be not sufficient to justify the relative investment on the specific technology by the vendor. If the operations performed by the external manufacturer are at the end of its processing and represent a termination of the product manufacturing, it's possible to arrange the transportation so as to ship the products completed directly to the buyer (avoiding the backward flow to the vendor) by reducing the entire Supply Chain costs. In the case considered it's not possible because the operation performed by the external manufacturer are intermediate operations and the products semi-finished must be shipped back to the buyer with other components in a specific kit assembled and tested by the Vendor before shipping the final product to the buyer.

As an explicit example we can refer to the production of structural reinforcement for the secondary structure of an aircraft (named "brackets"). The production cycle of these components starts with the bending of the brackets from the sheet metal (raw material) by the first tier supplier. Then, chemical processes are applied (sulphuric and acid anodizing) to the brackets from an external Manufacturer specialized and qualified for this operation (he must hold a NADCAP accreditation, http://www.pri-network.org/nadcap/). After the chemical treatment, the brackets are sent back to the first tier supplier for the final operation, before being shipped to the aircraft manufacturer for the final assembly. In particular, after the quality control of the brackets, these are collected with other aircraft components produced by the first tier supplier to be shipped to the aircraft manufacturer. This final operation, performed by the first tier supplier, precludes the delivery of the brackets directly from the external Manufacturer to the aircraft manufacturer.

Main aim of this paper is to study a supply chain that additionally to the common vendor–buyer relationship encompasses a third party external manufacturer that is supposed to collaborate with the vendor in an intermediate operation performed on the product. Moreover, this contribution does not consider explicitly contracting and pricing issues, that however are worthwhile of future development. More specifically, the developed models with third-party processing with an external Manufacturer are devoted to determine the optimal lot sizing policy, in order to minimize supply chain total cost, comparing the traditional agreement policy (TA) with the Vendor Managed Inventory with Consignment Stock policy (VMI-CS). As it is known from literature that VMI-CS gives better results in terms of supply chain total cost minimization than TA under specific value of the production-inventory parameters, the aim of this contribution is to investigate such an effect of the VMI-CS policy also considering the third-party processing with an external Manufacturer.

This particular setting has not been studied previously in literature and even if at a first look can be seen as a particular instance of a three level supply chain (like the model studied in Jaber & Goyal, 2008), this is not the case because the pivotal role of the vendor in the relationship with the external manufacturer constitutes a specific peculiarity of the model proposed, moreover the practical relevance of the problem addressed make it particularly important to practitioners who seek optimization arrangement for their relationship with third party processing suppliers.

The remainder of this paper is organized as follows. Literature review is presented in Section 2, while Section 3 describes the system considered. Section 4 introduces notation, assumptions and the main cost functions considered. Section 5 is devoted to the development of the mathematical models. Section 6 provides some numerical examples to illustrate the proposed models and in Section 7 sensitivity analysis on main parameters is offered. Finally, Section 8 concludes the paper and provides suggestions for future research.

2. Literature review

Coming back to the root of the analytical supply chain models, Goyal (1976) firstly introduced the idea of optimizing the joint cost of system that consists of a Vendor and a Buyer. He assumed the Vendor's production rate to be instantaneous with a lot-for-lot (LFL) shipment policy. The work of Goyal (1976) was successively extended by Banerjee (1986) who assumed a finite rate rather than an instantaneous production rate. Goyal (1988) revisited his earlier model assuming that the Vendor's inventory is accumulated and is delivered to the Buyer in shipments of equal sizes. In these models, the optimal inventory and shipment policies for the two-echelon system were determined in the same manner as in Goyal (1976), i.e. optimizing the joint cost of system.

Following the works of Goyal and Banerjee, the basic JELS model has been extended in many different directions: a recent exhaustive review classified main extensions (Glock, 2012)

Following, the works of Hill (1997, 1999) considered a policy where the Vendor's lot size is an integer multiplier of that of the Buyer. In Hill's models, the entire lot is produced first, and then it is delivered to the Buyer in batches of equal or unequal sizes. Valentini and Zavanella (2003) are supposed to be the first to study the consignment stock (CS) practice in a single Vendor-single Buyer system. Braglia and Zavanella (2003) analytically investigated the CS policy in a two-level supply chain, which model has been investigated further by Zanoni and Grubbstrom (2004) who showed that the optimal values of the model decision variables can be solved analytically, considering the base case of Consignment Stock model as proposed by Braglia and Zavanella (2003).

The CS policy allows the Vendor to move its inventory to the Buyer's warehouse when it is cheaper. The Buyer would benefit from this, as no dealing with overstocking or under-stocking is required. The Buyer will also benefit by paying for items as they are consumed, which frees its capital. The comparison between the numerical results of Hill's and CS policies, available in Braglia and Zavanella (2003), shows that, under some conditions, the CS policy might be a strategic and profitable option for managers to consider when deciding on how much to order, when to order, and where to stock their inventories. Tang, Zanoni, and Zavanella (2007) also showed how a CS agreement may improve the performance of an inventory system in stochastic environments. The Vendor may also benefit from adopting a CS policy when multi-Buyers are considered (Zavanella & Zanoni, 2006), when imperfect production process with/without restoration interruptions is considered (Bazan, Jaber, Zanoni, & Zavanella, 2014) and when demand is stock-dependent on the number of items on display in the buyer's store (Zanoni & Jaber, 2015). Moreover, Zanoni, Jaber, and Zavanella (2012) presented an enhancement of the VMI with consignment agreement model considering learning in production process at the Vendor's side. Zanoni, Mazzoldi, and Jaber (2014) showed that Vendor Managed Inventory system with Consignment