



Heuristic method on solving an inventory model for products with optional components under stochastic payment and budget constraints

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ABSTRACT

In recent years, enterprises must manage the inventory of items produced by multiple components and the interactions among those items because of a growing emphasis on modularization and customization. In fact, a powerful and affordable information technology system can make the continuous review of inventory more convenient, efficient, and effective. Thus, a (Q, r) model is developed in this study to find the optimal lot size and reorder point for a multi-item inventory model with interactions between necessary and optional components. In order to accurately approximate the related costs, the service cost is introduced and defined in proportion to the service level. In addition, the service costs are incorporated with budget constraint because the firm's strategy could influence the choice of service level. The proposed model is formulated as a nonlinear, discrete optimization problem and some known procedures are revised to solve this problem. The results are compared with other models and show that the revised procedure performs better than the N-R procedure leading to the important insights about inventory control policy. The results also reveal that the total amount allowed for the issued orders is paid at the time an order is received when the budget constraint is elastic.

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1. Introduction

In recent years, globalization and customization have led enterprises to make a greater focus on effective and efficient business processes. Most importantly, modularization and postponement are the two key issues in product and process design for the enterprises to globalization and customization. Modularization and postponement imply a product design approach whereby the product is assembled from a set of standardized units, and then these different components (or modules) are assembled closer to the point of purchase. Many studies have investigated these concepts from different aspects and have concluded that these two concepts help to reduce uncertainty and forecasting errors with regard to demand (Ernst & Kamrad, 2000; Swaminathan & Tayur, 1998, 1999). Hence, modularization and postponement have a large impact on inventory management, especially for a multi-item inventory system.

The (Q, r) model is a continuous review inventory model, an order of constant size Q is placed whenever the inventory position drops to a fixed reorder point r . Traditional multi-item inventory models with independent demand under resource constraints are discussed in the literature (Hadley & Whitin, 1963; Johnson &

Montgomery, 1974). However, these kinds of multi-item inventory models with independent demand do not comply with the concept of modularization. In fact, there are interaction effects that have been overlooked in the multi-item inventory with independent demand. Additional demand could depend on the increasing or decreasing demand of other items or the presence for others. Balakrishnan, Pangburn, and Stavroulakis (2004) sought to develop insights for managing demand-stimulating inventories using an order-sizing model that incorporated inventory-dependent demand. Moreover, the multi-item inventory model with dependent demand under the consideration of the joint demand fulfillment (Hausman, Lee, & Zhang, 1998) does not fit the concept of postponement well.

Meanwhile, substantial research on inventory management with a continuous review inventory policy has concentrated on the performance of (Q, r) policies by formulating the average inventory, stockouts, and other criteria as functions of Q and r . For example, stochastic demand, variable lead-time, backorder cost, service level constraint (or filled rate), budget constraint, storage space constraint, and other workload constraints have been integrated into the (Q, r) system (Parker, 1964; Schrady & Choe, 1971; Yano, 1985).

The (Q, r) model is a heuristic approximating method for a fixed reorder quantity policy with backorders. Traditionally, the average annual variable costs discussed in the (Q, r) model include procurement costs, inventory carrying (holding) costs, and stockout costs.

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Inventory carrying cost and backorder cost are inherently difficult to measure, and they are treated directly proportional to the length of time for which the unit remains in inventory and can be assumed as a small proportion of the number of backorders, respectively. By examining the above costs, one can find that they cannot represent the cost in the real world when the service level (defined by Hillier & Lieberman (2001)) is considered. This has drawn the attention of some researchers. For instance, inventory carrying cost was assumed as directly related to service levels in the assembly sequences (Swaminathan & Tayur, 1999), and safety stock was assumed as directly related to service level (Collier, 1982; Dogramaci, 1979), as well as other considerations (Rosling, 2002).

In fact, a higher service level results in a larger heuristic approximating error because increasing the costs of labor, facilities, and related services is necessary to achieve it. One can find that the greater the reorder point is, the higher the service level (and thus the higher the service cost) will be. The cost associated with these additional heuristic approximating errors is called the service cost, which is not linearly dependent on the ordering cost, the holding cost, or the shortage cost, but is dependent upon the service level. This implies that the service cost is proportional to (or is positively related to) the service level. Thus, one can evaluate the service cost using the following definition to reduce the risk of overestimating the decision variables Q and r when the service level is increased.

Definition 1. The service cost is proportional to the service level. That is,

$$SC = \kappa F(r)$$

where κ : the service cost rate; $F(r)$: represents the service level.

Some different aspects of cost have been introduced into different models in the literature. For example, the complexity cost (the cost in indirect functions caused by component variety) was taken into account in the component design problem (Thonemann & Brandeau, 2000), a design cost associated with flexibility in the assembly sequence and the design cost were considered in the component design problem (Dogramaci, 1979; Swaminathan & Tayur, 1999), the production cost and R&D cost were included in the component design problem (Thomas, 1991). These additional considerations make models more complex and the closed form solutions become unavailable. Thus, iterative algorithms are used to find a solution close to the optimal one. Many studies have presented some efficient solution procedures to obtain the approximating decision rules for such problems (Bhattacharya, 2005; Chen, 2005; Ghezavati, Jabal-Ameli, & Makui, 2009; Hausman et al., 1998; Li & Kuo, 2008; Lin, Shie, & Tsai, 2009; Swaminathan & Tayur, 1999; Thomas, 1991).

From the above discussion, modularization and customization have increased the importance of the multi-item inventory problem with interactions among those items. Moreover, having optional components be dependent on the necessary components while the optional components are independent of each other is crucial to the decision makers. In addition, incorporating service costs in the annual average costs can reduce the risk of overestimating the variables Q and r .

As far as the purchasing cost is concerned, most researches have assumed that purchasing costs are paid at the time an order is placed. However, it has become acceptable in these days that the payment is due upon order arrival. Since the inventory level is a random variable as an order arrives, the maximum investment in inventory is also random. This kind of random behavior is discussed in Wang and Hu (2008). Therefore, the concept of payment is due upon order arrival should be included in current discussion.

The purpose of this research is to explore the inventory control problem based on modularization and customization, and to solve the problem from two situations, depending upon if the service level of the necessary component is given. In the proposed system, the necessary component and some of the optional components will assemble the products (depend on the choice of customers) when the orders received. Hence, a multi-item inventory model is proposed and a simple heuristic approximating procedure is developed to solve it. In addition, it is assumed that each of the components has a different cycle time on inventory control, and the Lagrangian relaxation method is used to guarantee that the total available capacity will not exceed at the eventual points when all orders reach.

The rest of the paper is organized as follows: in Section 2, a problem is formulated to evaluate the multi-item inventory control with interactions among items under a budgetary constraint. The procedure to solve the proposed model is developed in Section 3, and the case of the necessary and optional components with a bivariate normal distribution is given in Section 4. Finally, Section 5 includes a summary and the conclusions.

2. Model formulation

2.1. Notations

The following notations are used to formulate the proposed model.

X	the random variable of the demand during the lead time for the necessary component V (vanilla box)
Y_j	the random variable of the demand during the lead time for the optional component j
A_V	the fixed cost for procuring the necessary component V
A_{oj}	the fixed cost for procuring the optional component j
C_V	the unit variable procurement cost for the necessary component V
C_{oj}	the unit variable procurement cost for the optional component j
D_V	the expected annual demand of the necessary component V
D_{oj}	the expected annual demand of the optional component j
$f_{X,Y_j}(x,y)$	the joint probability density function of X and Y_j
$F_{X,Y_j}(x,y)$	the joint cumulative distribution function of X and Y_j
$f_X(x)$	the marginal density function of X
$F_X(x)$	the marginal cumulative distribution function of X
$f_{Y_j X}(y x)$	the conditional density function of Y_j given $X = x$
$F_{Y_j X}(y x)$	the conditional cumulative distribution function of Y_j given $X = x$
h_V	the carrying cost of the necessary component V
h_{oj}	the carrying cost of the optional component j
κ_V	the service cost rate of the necessary component V
κ_{oj}	the service cost rate of the optional component j
p_V	the unit shortage cost of the necessary component V
p_{oj}	the unit shortage cost of the optional component j
Q_V	the order size of the necessary component V
Q_{oj}	the order size of the optional component j
r_V	reorder point of the necessary component V
r_{oj}	reorder point of the optional component j
SC_V	the service cost of the necessary component V
SC_{oj}	the service cost of the optional component j
β	the available budget limit when all orders reach a simultaneous peak
η	smallest acceptable probability that total investment is within budget
μ_V	mean of the lead time demand for the necessary component V

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