Evaluation of Component Commonality Strategies in Supply Chain Environment

Jack C. P. Su*, Yih-Long Chang** and Johnny C. Ho***

Abstract

This paper evaluates three component commonality strategies in supply chain environment: Distinctive Part (DP), Pure Component Commonality (PCC), and Mixed Component Commonality (MCC) strategies. DP is where all products consist of distinctive parts and no common component is used, while PCC is where one or more parts from different products are completely replaced by common components. In MCC, unlike PCC, it allows partial substitution of distinctive parts with common components. We develop models to analyze these strategies for both the constant and stochastic demands. The solution to minimizing the total inventory cost is presented. For constant demand, MCC is the worst choice and PCC is the best for the case of low common component price, high ordering cost, or high interest rate. For stochastic demand, PCC is the best for the case of low common component price, high demand variation, high ordering cost, long lead time, or high interest rate. However, MCC can be used to reduce inventory cost if the demand variation is high. Other conditions for the appropriateness of MCC are also discussed.

Keywords: Supply chain management; Component commonality; E-business; Operations strategy

1. Introduction

Internet based e-business is getting more and more common. It provides companies with a low cost platform to interact with their customers and has become an essential tool to offer customized products. However, beyond its popularity, most of e-business are struggling because of poor supply chain management [7]. Gural et al. [8] finds that the Internet based e-business does not eliminate the need for physical logistics. In fact, the Internet based e-business has only elevated its importance. While the information flow among supply chain partners can be efficiently managed over the Internet, companies need to rely on a complementary physical logistics system to distribute tangible products to their clients. Van Hoek [17] claims that the sub-standard performance of the supply chain is hampering the turnover and revenues of e-business. Hence, to fully utilize the Internet based e-business

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model as a means to provide customized products and to increase customer satisfaction, companies involving in e-business must pay close attention to the issues related to supply chain management.

Figuring out how to provide a high degree of product variety in a cost efficient way has long been a major challenge for supply chain management, this is especially true for Internet based e-business. Product variety can be defined on two dimensions: the breadth of products that a firm offers at a given time, and the rate at which the firm replaces existing products with new products. Both dimensions of product variety have steadily increased in many industries [5,15,16].

However, companies providing a wide variety of products are facing increasing difficulties in estimating demand, controlling inventory, and providing high service levels for customers. Component commonality (CC) is one of the most popular supply chain strategies to cope with these challenges. It advocates using a common component to replace a number of distinctive components in various products so that the safety stock can be reduced due to risk pooling. Ma et al. [11] claims that CC is now attracting attention as companies are compelled to provide and manage an increasing product variety and to compete in supply chain excellence in a global market. Naim and Barlow [13] studies how the UK house-building industry uses CC to provide customized housing. Ford is adopting common components to minimize inventory in the supply chain [12]. Baijko [2] argues that the frequent use of common components is essential to supply chain agility. Perez and Sanchez [14] find that success of just-in-time delivery depends on the use of common component. As indicated by the above references, CC plays an important role in supply chain management. Therefore, we are motivated to evaluate three CC strategies in this paper.

The study of CC dates back to Collier [3] when he defined an index to measure the degree of component commonality. He finds that higher degree of component commonality is significantly associated with the reduction in manufacturing cost. Baker et al. [1] present a two-product, two-level, single period inventory model to study the effect of commonality on the number of units in stock. Their model minimizes the number of units in stock under a specified service level and the normally distributed demand scenario. They show that by introducing commonality the total number of units in inventory is reduced and the inventory level of the common component is lower than the total inventory level of the two components it has replaced. Gerchak et al. [6] extend the work of Baker et al. and minimize the total material acquisition cost
under the general demand distribution case. Eynan and Rosenblatt [4] extend Baker et al.’s work by allowing the price of the common component to exceed the price of the common component that it replaces and analyze cases in which commonality is still economically justified. Hillier [9] extends the model of Eynan and Rosenblatt [4] to consider the multiple-period case, and concludes that benefits of commonality are lessened in the multiple-period case.

Our study departs from the previous research in two aspects. First, all of the previous research focuses on the comparison between Distinctive Part (DP) strategy and Pure Component Commonality (PCC) strategy. The DP strategy is where all products consist of distinctive parts and no common component is used (see Figure 1). The PCC strategy is where one or more distinctive parts are completely replaced by a common component (see Figure 2). We call those parts which can be replaced by the common component as the replaceable parts (e.g. parts \(a\) and \(b\) in Figure 1). In this paper, we propose a new strategy called Mixed Component Commonality (MCC) strategy. In the MCC strategy, unlike the PCC strategy, it allows partial substitution of replaceable parts with common components (see Figure 3).
An example of the MCC strategy can be observed from the PC industry. Most of the PC manufacturers utilize the Pentium CPU in their high-end PCs and the Celeron CPU in their low-end PCs. There are generally three types of motherboard chip sets available: the chip set that support only the Pentium CPU; the chip set that supports only the Celeron CPU; and the chip set that supports both CPUs. PC manufacturers often use combinations of these three types of chip sets in their PCs.

An inevitable outcome of the MCC strategy is the increase in the number of parts inventoried. In the past, it was very expensive to design, produce, and manage an extra part and hence prohibited the adoption of the MCC strategy. However, the trend towards outsourcing has made the MCC strategy more feasible today. A company can easily order different parts from its suppliers. In addition, the adoption of the information technology in inventory management has reduced the cost and complexity of managing a very large number of parts. For these reasons, it is important to consider the MCC strategy in our study.

The second aspect distinguishing our study from the previous research is that we extend the previous models by considering all inventory related costs, including the ordering cost and shortage cost.

In this paper, we develop two models to analyze both the constant and the stochastic demand scenarios. The solution to minimizing the total inventory cost is presented and the managerial insights are derived from our analysis. We find that when the demand is constant, the MCC strategy is never beneficial. In addition, the PCC strategy is preferred when either the price of the common component is low, the ordering cost is high, or the interest rate is high. On the other hand, when the demand is stochastic, we find that the MCC strategy can
be used to reduce inventory cost if the demand variation is high. The PCC strategy is preferred when either the price of the common component is low, the demand variation is high, the ordering cost is high, the lead time is long, or the interest rate is high. Furthermore, we conclude that when demand variation is moderate, unit shortage cost is not a significant factor in the choice of component commonality strategies. In the case of high demand variation, the PCC strategy is preferred when shortage cost is high, and the MCC strategy can be adopted for a range of moderate shortage cost.

The remainder of this paper is organized as follows. Section 2 develops the models for both the constant and stochastic demand cases. We present the solution results and managerial insights derived from these models in Section 3. Section 4 summarizes the study and discusses potential areas for future research.

2. Models

Suppose that a firm manufactures a product family consisting of two products, A and B. Product A is oriented for higher end market; while product B is aimed at lower end market. We use a to denote a subsystem of A and b to denote a subsystem of B. Subsystems a and b may be replaced by a common component, m. The common component, m, generally equips with extended functions such as additional conjunction to attach to two different end products and has to meet the quality standard of the higher end product, A. Hence, it is reasonable to assume the unit price of m is more expensive than the replaceable parts. That is, \( P_m \geq P_a \geq P_b \), where \( P_j, j = m, a, b \) are the unit price for replaceable parts a and b, and common component, m, respectively.

In this study, we focus on the internal choice of component commonality strategies; hence we assume that all components are outsourced from the same or similar suppliers and have the same constant delivery lead-time and ordering cost. Since the components are outsourced, there is no additional cost involved in the design, development, and manufacturing of the components. Therefore, inventory related costs – unit cost, ordering cost, inventory holding cost, and shortage cost – are the only ones of interest.

We study both the constant demand and stochastic demand problems. The following notation is defined for use in this paper.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>( D_i )</td>
<td>Annual demand for end product i, ( i = A, B )</td>
</tr>
<tr>
<td>( P_j )</td>
<td>Unit price of subsystem j, ( j = a, b, m )</td>
</tr>
<tr>
<td>( A )</td>
<td>Ordering cost</td>
</tr>
<tr>
<td>( L )</td>
<td>Lead time</td>
</tr>
</tbody>
</table>
Random variable representing demand for subsystem $j$ over lead time with mean $\mu_j$ and standard deviation $\sigma_j$, $j = a, b, m$

Degree of commonality, i.e., percentage of the product $i$ produced by using the common component, $i = A, B$

Order quantity of subsystem $j$, $j = a, b, m$

Annual interest rate

Unit inventory holding cost per period of time of subsystem $j$, $j = a, b, m$

Expected unit of shortage during lead time of subsystem $j$, $j = a, b, m$

Unit shortage cost of subsystem $j$, $j = a, b, m$

### 2.1 Constant Demand Problem

In this basic model we assume the demands of products $A$ and $B$ are constant. The total annual material cost is:

$$
P_a(1 - e_a)D_A + P_b(1 - e_b)D_B + P_m(e_aD_A + e_bD_B)$$

The first two terms represent the material cost to acquire $a$ and $b$; and the third term denotes the material cost to acquire $m$. $(1 - e_a)$ and $(1 - e_b)$ are the percentages of demands fulfilled by replaceable parts $a$ and $b$. $(e_aD_A + e_bD_B)$ is the quantity of the common component $m$ ordered.

Since all the components are outsourced, the only setup cost is ordering cost. The total annual ordering cost is

$$\frac{A(1 - e_a)D_A}{Q_a} + \frac{A(1 - e_b)D_B}{Q_b} + \frac{A(e_aD_A + e_bD_B)}{Q_m}$$

The total annual inventory holding cost is

$$h_a\left[\frac{Q_a}{2}\right] + h_b\left[\frac{Q_b}{2}\right] + h_m\left[\frac{Q_m}{2}\right]$$

The long-term average inventory position for part $j$ is $\frac{Q_j}{2}$, $j = a, b, m$.

The total annual cost of the constant demand problem is the summation of (1), (2), and (3). We will solve for $Q_a, Q_b, Q_m, e_a,$ and $e_b$ to minimize the total inventory cost in Section 3.
2.2 Stochastic Demand Problem

In real life the demand is rarely constant. For this reason, it is important to study how the different component commonality strategies perform in the stochastic demand environment. In this model, we assume the demands over lead time for components \( j, j = a, b, m \), are normally distributed with mean \( \mu_j \) and standard deviation \( \sigma_j \).

Since the demand over lead-time is stochastic, it is possible that there exists shortage during lead time. The expected shortage during lead time is defined as

\[
\bar{b}_j = \int_{s_j}^{\infty} (x_j - s_j) f_j(x_j) \, dx_j, \quad j = a, b, m
\]

where \( f_j(x_j) \) are probability density functions. The shortage cost is calculated as

\[
\frac{\pi_a \bar{b}_j D_A}{Q_a} + \frac{\pi_b \bar{b}_j D_B}{Q_b} + \frac{\pi_m \bar{b}_j (e_s D_A + e_s D_B)}{Q_m}
\]

Material cost and ordering cost are the same as the constant demand problem given as follows.

Material cost:

\[
P_a (1 - e_s) D_A + P_b (1 - e_s) D_B + P_m (e_s D_A + e_s D_B)
\]

Ordering cost:

\[
\frac{A(1 - e_s) D_A}{Q_a} + \frac{A(1 - e_s) D_B}{Q_b} + \frac{A(e_s D_A + e_s D_B)}{Q_m}
\]

To calculate the inventory holding cost, we first estimate the long-term average inventory position. Since the maximum inventory position during lead time is the order quantity plus safety stock or re-order point minus average demand over the lead time, i.e., \( Q_j + s_j - \mu_j \) and the minimum inventory position during lead-time is safety stock or re-order point subtract average demand over lead time, i.e., \( s_j - \mu_j \). Hence, the expected long-term average inventory position is:

\[
\frac{Q_j}{2} + s_j - \mu_j \quad j = a, b, m
\]

The inventory holding costs are estimated as:

\[
h_a \left[ \frac{Q_a}{2} + s_a - \mu_a \right] + h_b \left[ \frac{Q_b}{2} + s_b - \mu_b \right] + h_m \left[ \frac{Q_m}{2} + s_m - \mu_m \right]
\]
The total cost of the stochastic demand problem is the summation of Equations (4), (5), (6), and (7). We will solve for \( Q_a, Q_b, Q_m, s_a, s_b, s_m, e_a, \) and \( e_b \) to minimize the total inventory cost in the next section.

3. Solution Results and Managerial Insights

We now present the procedure for solving the constant and stochastic demand problems discussed in Section 2. Moreover, the solution results and managerial insights discovered by investigating the problems will be discussed.

3.1 Solution of Constant Demand Problem

Recall that the total cost function of this problem is:

\[
TC = P_a (1 - e_a) D_a + P_b (1 - e_b) D_b + P_m (e_a D_a + e_b D_b) +
\]

\[
\frac{A_a (1 - e_a) D_a}{Q_a} + \frac{A_b (1 - e_b) D_b}{Q_b} + \frac{A_m (e_a D_a + e_b D_b)}{Q_m} +
\]

\[
h_a \left[ \frac{Q_a}{2} \right] + h_b \left[ \frac{Q_b}{2} \right] + h_m \left[ \frac{Q_m}{2} \right]
\]

To find the optimal order quantity, we first set

\[
\frac{\partial TC}{\partial Q_a} = 0
\]

and solve for \( Q_a \), and we obtain

\[
Q_a^* = \sqrt{\frac{2A (1 - e_a) D_a}{h_a}}
\]

Similarly, we obtain

\[
Q_b^* = \sqrt{\frac{2A (1 - e_b) D_b}{h_b}}
\]

\[
Q_m^* = \sqrt{\frac{2A (e_a D_a + e_b D_b)}{h_m}}
\]

Substitute \( Q_a^* \), \( Q_b^* \), and \( Q_m^* \) into Equation (8). Now the total cost function is reduced to a function of \( e_a \) and \( e_b \), i.e., \( TC = f(e_a, e_b) \).

To find the optimal degree of commonality, we set

\[
\frac{\partial TC}{\partial e_a} = 0
\]

and get
Again, we set $\frac{\partial TC}{\partial e_b} = 0$ and get

$$D_b(P_w - P_p) = \frac{(2h_m A D_{b_0})}{2(1-e_p)} + \frac{h_m A}{2(e_p D_A + e_b D_B)} D_B = 0 \tag{13}$$

We solve Equations (12) and (13) simultaneously to determine the optimal degree of commonality, $e_a^*$ and $e_b^*$. However, there is no simple closed form solution.

To find an alternative way to solve this problem analytically, we now exploit the concavity property of the cost function.

**Lemma 1:** The total cost function is concave in $e_a$ and $e_b$.

**Proof:**

$$\frac{\partial^2 TC(e_a, e_b)}{\partial e_a^2} \frac{\partial^2 TC(e_a, e_b)}{\partial e_b^2} - \frac{\partial^2 TC(e_a, e_b)}{\partial e_a \partial e_b} =$$

$$= (2(1-e_a)) \frac{1}{2} (2(1-e_b)) \frac{1}{2} (h_m A D_A) \frac{1}{2} (h_m A D_B) \frac{1}{2} +$$

$$+ (2(1-e_a)) \frac{1}{2} (h_m A D_A) \frac{1}{2} (2(e_p D_A + e_b D_B)) \frac{1}{2} (h_m A) \frac{1}{2} D_A \frac{1}{2}$$

$$= - (2(1-e_a)) \frac{1}{2} (h_m A D_A) \frac{1}{2} - (2(e_p D_A + e_b D_B)) \frac{1}{2} (h_m A) \frac{1}{2} D_A \frac{1}{2} \leq 0 \tag{14}$$

$$\frac{\partial^2 TC(e_a, e_b)}{\partial e_b^2} =$$

$$= - (2(1-e_b)) \frac{1}{2} (h_m A D_B) \frac{1}{2} - (2(e_p D_A + e_b D_B)) \frac{1}{2} (h_m A) \frac{1}{2} D_B \frac{1}{2} \leq 0 \tag{15}$$

From Equations (14), (15), and (16), the total cost function is concave in $e_a$ and $e_b$. Since the total cost function is concave in $e_a$ and $e_b$, the optimal degree of commonality $e_a^*$ and $e_b^*$ may only assume either 0 or 1. For this reason, the
minimum cost must be at one of \( f(0,0) \), \( f(0,1) \), \( f(1,0) \), or \( f(1,1) \). From Equation (8), we obtain

\[
f(0,0) = P_a D_A + P_b D_B + \sqrt{2AD_Ah_a} + \sqrt{2AD_Bh_b}
\]

(17)

\[
f(0,1) = P_a D_A + P_b D_B + \sqrt{2AD_Ah_a} + \sqrt{2AD_Bh_m}
\]

(18)

\[
f(1,0) = P_a D_A + P_b D_B + \sqrt{2AD_Ah_m} + \sqrt{2AD_Bh_b}
\]

(19)

\[
f(1,1) = P_m(D_A + D_B) + \sqrt{2A(D_A + D_B)h_m}
\]

(20)

Since \( P_m \geq P_a \geq P_b \), then \( f(0,1) \) and \( f(1,0) \) must be greater than or equal to \( f(0,0) \). Hence the candidates for an optimal solution are reduced to only two, i.e., \( f(0,0) \) or \( f(1,1) \). In addition, numerical examples can be used to demonstrate that there is no definitive inequality relationship between \( f(0,0) \) and \( f(1,1) \). Therefore, the optimal solution is either \( e_a = e_b = 0 \) or \( e_a = e_b = 1 \). In other words, we only need to compute \( f(0,0) \) and \( f(1,1) \) and select the one with a lower cost as an optimal solution. We summarize the above finding in the following lemma.

**Lemma 2:** Assuming \( P_m \geq P_a \geq P_b \), the optimal degree of commonality is either \( e_a = e_b = 0 \) or \( e_a = e_b = 1 \).

The optimal order quantity for \( a \), \( b \), and \( m \) can be calculated by substituting the optimal degree of commonality found by Lemma 2 into Equations (9), (10), and (11).

From Lemma 2, since the minimum cost can be achieved by using DP strategy (\( e_a = e_b = 0 \)) or PCC strategy (\( e_a = e_b = 1 \)), we can now conclude that MCC strategy is not useful in the constant demand problem.

### 3.2 Strategy Comparison in Constant Demand Environments

Besides solving the problem, it is important to know which component commonality strategy is preferred under various conditions. To do so, we first calculate the cost difference between the PCC strategy and DP strategy as follows:

\[
\Delta TC = f(1,1) - f(0,0) = \\
(D_A)(P_m - P_a) + (D_B)(P_m - P_b) + \\
\sqrt{2Ah_m(D_A + D_B)} - \sqrt{2AD_Ah_b} - \sqrt{2AD_Bh_b}
\]

(21)

We assume the demands of products \( A \) and \( B \) are proportional to a total demand \( D \); hence, \( D_A = K_A D \) and \( D_B = K_B D \). Since the unit holding cost is equal to the price times interest rate, i.e., \( h_j = P_ji, j = a, b, m \). Equation (21) becomes
\[ \Delta TC = f(1,1) - f(0,0) = \\
( K_a D)(P_m - P_a) + ( K_b D)(P_m - P_b) + \\
\sqrt{2AP_m i(K_a D + K_b D)} - \sqrt{2AK_a DP_m i} - \sqrt{2AK_b DP_m i} \]

We first study how change of \( P_m \) impacts the choice of the strategies.

**Lemma 3:** \( \Delta TC \) is an increasing function with respect to \( P_m \).

**Proof:**

\[
\frac{\partial \Delta TC}{\partial P_m} = K_a D + K_b D + (2P_m)^{\frac{1}{2}} \left( A i(K_a D + K_b D) \right)^{\frac{1}{2}} > 0.
\]

From Lemma 3, when \( m \) is more expensive, the cost of PCC strategy is higher. Thus, the DP strategy is preferred. Next, we discuss how the ordering cost will impact the choice of the strategy.

**Lemma 4:** \( \Delta TC \) is a decreasing function with respect to \( A \).

**Proof:**

\[
\frac{\partial \Delta TC}{\partial A} = (2A)^{\frac{1}{2}} \left( P_a i(K_a D + K_b D) \right)^{\frac{1}{2}} - \\
(2A)^{\frac{1}{2}} \left( P_b i(K_a D) \right)^{\frac{1}{2}} - (2A)^{\frac{1}{2}} \left( P_a i(K_b D) \right)^{\frac{1}{2}}
\]

Because \( P_m \geq P_a \geq P_b \), the above equation is less than or equal to

\[
(2A)^{\frac{1}{2}} \left( D \right)^{\frac{1}{2}} \left( P_a (K_a + K_b) \right)^{\frac{1}{2}} - (P_a K_a)^{\frac{1}{2}} - (P_b K_b)^{\frac{1}{2}}
\]

From Lemma 4, when the ordering cost is higher, the cost of DP strategy is higher and the PCC strategy is preferred. The reason is that in PCC strategy, a common component \( m \) is used so that the ordering cost is lower due to order pooling. As a consequence, the larger that the ordering cost is, the larger the saving is.

**Lemma 5:** \( \Delta TC \) is a decreasing function with respect to \( i \).

**Proof:**
\[
\frac{\partial \Delta TC}{\partial t} = (2i) \left( P_m A(K_J + D_a) \right) \frac{1}{\bar{t}} \nabla^\top + (2i) \left( P_m A(D_a) \right) \frac{1}{\bar{t}} \nabla^\top - (2i) \left( P_m A(\Delta K_a) \right) \frac{1}{\bar{t}} \nabla^\top = (2i) \left( \bm{DA} \right) \frac{1}{\bar{t}} \left\{ \left( P_m (K_J + K_b) \right) \frac{1}{\bar{t}} - \left( P_m K_J \right) \frac{1}{\bar{t}} - \left( P_m K_b \right) \frac{1}{\bar{t}} \right\}
\]

Similar to the proof of Lemma 4, where \( P_m \geq P_a \geq P_b \), the above equation is less than or equal to
\[
(2i) \left( \bm{DA} \right) \frac{1}{\bar{t}} \left\{ \left( P_m (K_J + K_b) \right) \frac{1}{\bar{t}} - \left( P_m K_J \right) \frac{1}{\bar{t}} - \left( P_m K_b \right) \frac{1}{\bar{t}} \right\}
\]

Theoretically, a higher interest rate increases the unit holding cost. Since the price of the common component is more expensive, so in a high interest rate environment, the unit holding cost for the common component increases more than that of the replaceable parts. Consequently, the DP strategy is preferred. On the other hand, higher holding cost reduces the optimal order quantity and in turn reduces the average inventory level. Since it is more expensive to hold the common component, lower inventory levels benefit the PCC strategy. The bottom line is that without proof it remains unclear how the interest rate will impact the choice between these two strategies. From Lemma 5 we prove that when the interest rate is higher, the cost of the DP strategy is higher. Therefore, the PCC strategy is preferred.

In short, we conclude that the PCC strategy is preferred when the price of common component is lower, the order cost is higher, and/or the interest rate is higher.

### 3.3 Solution of Stochastic Demand Problem

From Equations (4), (5), (6), and (7), the total cost function for stochastic demand is:

\[
TC = P_m (1 - e_s) D_J + P_m (1 - e_s) D_b + P_m (e_s D_J + e_s D_b) +
\frac{A(1 - e_s) D_J}{Q_s} + \frac{A(1 - e_s) D_b}{Q_s} + \frac{A(e_s D_J + e_s D_b)}{Q_s} +
\frac{h_s \left[ \frac{Q_s}{2} + s_s - \mu_s \right]}{Q_s} + \frac{h_s \left[ \frac{Q_s}{2} + s_s - \mu_s \right]}{Q_s} + \frac{h_s \left[ \frac{Q_s}{2} + s_s - \mu_s \right]}{Q_s} +
\frac{\pi_s \bar{D}_J}{Q_s} + \frac{\pi_s \bar{D}_b}{Q_s} + \frac{\pi_s \bar{D}_a + e_s D_J}{Q_s} + \frac{\pi_s \bar{D}_b + e_s D_b}{Q_s} + \frac{\pi_s \bar{D}_a (e_s D_J + e_s D_b)}{Q_s}
\]

Unlike the constant demand problem, the stochastic demand problem does
not have a nice closed form solution. We therefore solve this problem numerically.

The stochastic demand problem carries two important properties:

1. There is no singular point with respect to $e_a$ and $e_b$ when $0 < e_a < 1$ and $0 < e_b < 1$.

2. Given $e_a$ and $e_b$, solving the stochastic demand problem is equivalent to solving three independent $(s, Q)$ problems.

The first property ensures that there will be no sudden jump in total cost when we search along $e_a$ and $e_b$. For this reason, we can search our optimal solution along $e_a$ and $e_b$ in a discrete manner. The interval chosen for each search is 0.01. So the complete search consists of 10,000 possible combinations of $e_a$ and $e_b$. The solution of $(s, Q)$ problem is based on the procedure discussed in Johnson and Montgomery [10].

3.4 Strategy Comparison in Stochastic Demand Environments

Since there is no closed form solution to the stochastic demand problem, the managerial insights are derived by numerical studies. Our study is based on a numerical example taken from Johnson and Montgomery [10] in which $D_A = 10,000$, $D_B = 20,000$; the standard deviations of demands are set to 20%; the ordering cost is $70; the interest rate is 20%; $P_m = $5.05, $P_a = $5.00, and $P_b = $4.95; the unit shortage cost is $1.50; and the lead time is two weeks. To test the effect of a given factor, we fix the other parameters and vary the factor to cover a very broad range. We first study how the price of the common component impacts the choice of the strategy.

**Observation 1:** The DP strategy is preferred when the price of the common component is high.

We vary $P_a$ from $4.00 to $5.50. From Figure 4, when the price of the common component is higher, the DP strategy is preferred. This observation is consistent with our analysis in Lemma 3. However, Figure 4 also shows that it is not worthwhile to use the common component even when it is just a few cents more expensive than the replaceable parts. The reason is that unlike the single period model, the lower safety stock implies a firm can buy fewer components. For a multiple period model, although the PCC strategy allows fewer safety stock inventories, the total number of components purchased is unchanged since all demands are eventually met.
Observation 2: The PCC strategy is preferred when the demand variation is high.

To test the effect of demand variation, we fix the values of other factors and vary the standard deviations of the total demand from 10% to 100%. From Figure 5, when the demand variation is high, the PCC strategy is preferred because the benefit of using the common component to pool demand variation outweighs the extra cost of buying it. It is also worth noting that for product B, when the demand variation is more than 70%, the minimal cost is achieved by using the MCC strategy; i.e., use both replaceable part b and common component m. This leads to our next observation.

Observation 3: The MCC strategy could be used to reduce total cost when demand variation is high.

Observation 4: The PCC strategy is preferred when the ordering cost is high.

To test the effect of ordering cost, we vary the ordering cost from $70 to $1,400. From Figure 6, when the ordering cost is high, the PCC strategy is preferred. This observation is consistent with our finding in Lemma 5.
Observation 5: The PCC strategy is preferred when the lead time is long.

To test the effect of lead time, we vary the lead time from two weeks to forty weeks. From Figure 7, when the lead time is longer, the PCC strategy is preferred. The reason is that when lead time is longer, the unit of demand variation during lead time becomes larger and the benefit of using the common component to pool demand variation becomes larger.

Observation 6: The PCC strategy is preferred when the interest rate is high.

To test the effect of interest rate, we vary the interest rate from 20% to 100%. From Figure 8, when the interest rate is high, the PCC strategy is preferred. This observation is consistent with our finding in Lemma 5.

Observation 7: In a moderate demand variation environment, the unit shortage cost is not a significant factor in the choice of the strategies.

To test the effect of shortage cost, we vary the unit shortage cost from $1.50 to $30.00 dollars. However, from Figure 9, the effect of shortage cost is not significant in this scenario. The DP strategy is always preferred no matter how high the shortage cost is. To further verify this finding, we set up another scenario by reducing $D_A$ from 10,000 to 1,000 and $D_B$ from 20,000 to 2,000. The PCC strategy is preferred when the unit shortage costs vary from $1.50 to
Figure 6 The Effect of Ordering Cost

Figure 7 The Effect of Lead Time

$30.00. Figure 10 again shows that the effect of shortage cost is not significant. The PCC strategy is always preferred no matter how high the shortage cost is.
We therefore conclude that the unit shortage cost is not a significant factor in the choice of the strategies when the demand variation is moderate (20%).

Theoretically, when the shortage cost is high, the \((s, Q)\) system will automatically set a higher re-order point, \(s\), to prevent the expensive shortages; consequently this will increase the inventory level. Since it is more expensive to carry the common component, this phenomenon makes the DP strategy more attractive. On the other hand, when the shortage cost is high, it is also important to pool the demand variation to minimize the number of shortages. This makes the PCC strategy more attractive. From our observation, in a moderate demand variation environment, none of these two effects dominates the other; hence, the unit shortage cost becomes an insignificant factor.

**Observation 8:** In a high demand variation environment, the PCC strategy is preferred when the unit shortage cost is high.

In this experiment, we setup a high demand variation scenario (60%). When the unit shortage cost is high, the benefit of using the common component to pool demand variation outweighs the cost of higher inventory level.

![Figure 8 The Effect of Interest Rate](image-url)
Figure 9 The Effect of Unit Shortage Cost in Moderate Demand Variation Environments (DP is preferred)

Figure 10 The Effect of Unit Shortage Cost in Moderate Demand Variation Environments (PCC is preferred)
As shown in Figure 11, when the unit shortage cost is between $4.50 and $10.50, the MCC strategy is able to minimize the cost of product B. The optimal strategy switches to the PCC strategy when the unit shortage cost is larger than $10.50. Lastly, Table 1 summarizes the results of all eight observations.

### Table 1 A Summary of Observations

<table>
<thead>
<tr>
<th>Preferred Strategy</th>
<th>Price of Common Component</th>
<th>Demand Variation</th>
<th>Setup Cost</th>
<th>Lead Time</th>
<th>Interest Rate</th>
<th>Shortage Cost (moderate demand variation)</th>
<th>Shortage Cost (high demand variation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Long</td>
<td>High</td>
<td>Not significant</td>
<td>Low</td>
</tr>
<tr>
<td>DP</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Short</td>
<td>Low</td>
<td>Not significant</td>
<td>High</td>
</tr>
</tbody>
</table>

4. Conclusion and Future Research

Component commonality is an important option for firms facing the increasing challenges due to amplified product variety. In this paper, we evaluate three different component commonality strategies, i.e., DP, PCC, and MCC, and discuss the conditions under which one is preferred. We develop two mod-
els to analyze both the constant and the stochastic demand scenarios. The solution to minimizing the total inventory cost is presented and the managerial insights are derived from our analysis. We find that when the demand is constant, the MCC strategy is never beneficial. In addition, the PCC strategy is preferred when the price of the common component is low, the ordering cost is high, and/or the interest rate is high. On the other hand, when the demand is stochastic, we find that the MCC strategy can be used to reduce inventory cost if the demand variation is high. The PCC strategy is preferred when the price of the common component is low, the demand variation is high, the ordering cost is high, the lead time is long, and/or the interest rate is high. Furthermore, we conclude that when demand variation is moderate, unit shortage cost is not a significant factor in the choice of component commonality strategies. In the case of high demand variation, the PCC strategy is preferred when shortage cost is high, and the MCC strategy can be adopted for a range of moderate shortage cost.

There are several opportunities to enrich our study in the future. First, we assume all parts and modules are outsourced and all product design and development costs are excluded. In future research, we will include these costs in our models and study the issues regarding the coordination between product development and component commonality strategy. Second, we assume that all components are outsourced from the same or similar suppliers and that the ordering costs are very similar. Future research may extend our models to the multiple suppliers’ problem, where each supplier has different capacity; ordering cost; and quantity discount scheme, to examine the impact of vendor selection.

References


