Supply chain focus dependent sensitivity of the point of product differentiation

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Supply chain focus dependent sensitivity of the point of product differentiation

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Customer preferences for variety in the product(s) with improved customer service and lower prices are forcing the supply chains to overhaul the current practices from design to operational level. Postponement or delayed differentiation of the products is one such strategy, primarily deployed in mass customisation settings. Life cycles are shrinking not only for individual products but for product families as well. In this context, supply chain responsiveness becomes one of the crucial factors that need to be effectively managed to succeed in the present day competitive markets. Our model, that considers inventory costs and the supply chain responsiveness costs would aid a supply chain manager to make informed decisions with regard to the ideal location for the point of differentiation (POD), while striking the right balance between holding costs and the supply chain responsiveness costs. We also make use of a dimensionless parameter called the ‘coefficient of inverse responsiveness’ that not only facilitates the introduction of responsiveness related costs into the model but also improves the scalability and simplifies the analysis and interpretation of the results. Based on the strategic model developed, we offer some context-specific counter-intuitive managerial insights with respect to the sensitivity of the location of the POD in a supply chain.

Keywords: supply chain strategy; supply chain configuration; point of differentiation; postponement; supply chain cycle time; coefficient of inverse responsiveness

1. Introduction

Postponement of product differentiation in a mass customisation setting is gaining popularity particularly in terms of inventory cost reduction and better operations management. Mass customisation has been described as providing ‘numerous customer chosen variations on every order with little lead time or cost penalty’ (Ahlstrom and Westbrook 1999). As the product variety increases, obtaining accurate demand forecasts for each item becomes more difficult, and the level of inventories that must be carried to meet demand increases (Timucin 2000). Mass customisation provides the good qualities of hand-crafted products (unique designs and customised service) and it also reflects the most important gain from mass production – low operating cost (Graman and Magazine 2006). The implied challenge for manufacturers is how to deal with the high demand uncertainty, resulting from the provision of many variants, whilst ensuring low operational costs are maintained, as well as short, reliable lead times (Skipworth and Harrison 2006). Skipworth and Harrison (2006) state that form postponement reduces the risks associated with make to stock (MTS) and improves responsiveness compared with engineered to order (ETO) or make to order (MTO) while enabling a high level of customisation.

It has been clearly demonstrated in the literature that introducing a common component that replaces a number of unique components reduces the overall level of safety stock required to meet service level requirements (Hillier 2000). Empirical evidence suggests that firms that match their supply chain structure to the type of product variety they offer outperform firms that do not make use of such opportunities (Randall and Ulrich 2001). In this context, the location of the point of differentiation (POD) in a supply chain would play a vital role in enhancing the competitiveness. Davila and Wouters (2007) suggest postponing the configuration of a product to customer’s specifications as late as possible in the supply chain. For reducing the costs and risks of product variety, the concept of postponing the configuration of the product has received considerable attention (e.g. Lee 1996; Lee and Tang 1998; Aviv and Federgruen 2001; Yang and Burns 2003). Nugroho (2013) differentiates between configurable products and customised products and analyses the appropriateness of adopting price and production postponement strategies in those contexts.

The number of performance metrics that one could consider to study the problem of the effectiveness of postponement is not only large but also depends on the context (strategic, operational, etc.) type of the product, nature of the

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markets etc. For example, Choi, Narasimhan, and Kim (2012) develop a postponement strategy that makes use of a system dynamics model in the context of a global production–distribution system by including variables such as shipping points, custom tariffs etc. Among the possible order winners cost and responsiveness turn out to be more crucial than others (Nazzal, Mollaghasemi, and Anderson 2006).

Given opportunities for postponement, we investigate the issue of the location of the POD as a supply chain configuration problem specifically addressing the issue of cheaper unique components and better inventory parameters at upstream stages, while simultaneously addressing the issue of supply chain responsiveness. The introduction of supply chain responsiveness concept is a novel feature of this research, which to the best of our knowledge has not attracted the requisite attention in the existing literature so far. Cavusoglu, Cavusoglu, and Raghunathan (2012) have also considered the extent of increase in the unit production cost under postponement though their goal was to explore the interaction between production postponement and information sharing. In contrast to the unique POD that we considered in our model, Banerjee, Sarkar, and Mukhopadhyay (2012) consider multiple decoupling points and study their inter-relationships using a multidimensional scaling method for a fuzzy supply chain system. Teimoury and Fathi (2013) propose an interesting model based on queuing approach integrating operations and marketing perspectives with similar goals as with our model; the crucial difference being the importance attached to supply chain lead time as a factor in our model that emphasises the modern day reality of declining life cycles not only for products but for product families as well.

With cost and supply chain cycle time, which we have used as a proxy for supply chain responsiveness as the two key order winners, we investigate the issue of whether it is advantageous to locate the POD at the last stage in a supply chain or if it is beneficial to shift the POD upstream. Our primary emphasis in this research is to investigate the sensitivity of the location of POD in the presence of mitigating factors such as cheaper unique components etc., given supply chain’s point of emphasis on the cost-responsiveness spectrum. Our proposed model is designed as a supply chain configuration problem that is strategic in nature and generic in its approach; hence, we do not address issues related to implementation specific to a given industry. Readers interested in implementation aspects of form postponement may refer to, e.g. a recent paper by Van Kampen and Van Donk (2014), wherein they investigate the effect of specific characteristics common in food processing industry on the operational performance of form postponement using a simulation model. Tse et al. (2012) propose a decision support system by integrating Case-Based Reasoning and Fuzzy logic to support and improve postponement implementation activities at third-party logistics companies. For those readers interested in empirical research related to postponement practices and their relationship with appropriate operational strategies may refer to Saghiri (2011) who has proposed and validated different constructs on postponement using confirmatory factor analysis.

In the context of our model, responsiveness is the ability of the supply chain to respond quickly to changing customer needs, preferences, options etc. in terms of supply chain cycle time, emphasis being on volume-related flexibility. With shrinking life cycles for product families, volume-related flexibility as a measure of responsiveness assumes critical importance and to the best of our knowledge is not addressed explicitly in the existing product postponement literature. One of the primary contributions of this research is the simultaneous introduction of responsiveness related costs along with the inventory costs into the model through the usage of a novel parameter called ‘coefficient of inverse responsiveness’ introduced by Vanteddu et al. (2007). We make use of the total cost expression for a serial supply chain stage as presented in Vanteddu, Chinnam, and Gusikhin (2011), as the initial building block for developing the necessary strategic framework in the context of product postponement for addressing the question of the sensitivity of the location of the POD.

The organisation of the remaining part of this paper is as follows. Proposed strategic postponement framework and the relevant mathematical analyses are presented in Section 2 (specifically Sub-sections 2.3–2.5). To benefit the readers and for the sake of continuity, we present the summarised version of the overall cost expression for a serial supply chain stage (building block), adopted from Vanteddu, Chinnam, and Gusikhin (2011) in Sub-section 2.2. We present the extended mathematical model and the relevant analyses in the context of product postponement in Sub-sections 2.3–2.5. In Section 3, an illustrative example is presented that investigates the issue of the location of POD for a supplier of wire harnesses to an automobile OEM facility. In Section 4, we present the managerial insights and the relevant numerical analyses are offered in Section 5. Last but not the least, conclusions and limitations are offered in Section 6.

2. Model description

2.1 Development of the mathematical expression for cost savings at a supply chain (SC) stage in postponement context

In this section, by taking into account inventory costs and SC responsiveness related costs for a stage in a serial supply chain we develop the necessary mathematical framework for the expected cost savings at stage ‘j’ if common product is differentiated into unique products at that stage. Inventory and responsiveness (a function of SC cycle time) related costs

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are the two important performance metrics that are considered in this model, which one could argue to be the two most important factors that drive the costs and affect the competitiveness in the present day highly competitive global markets. The concept of postponement and its attendant benefits are explored as the supply chain emphasis shifts from one end to the other on the cost-responsiveness spectrum.

By considering volume-related flexibility at a given stage as a proxy for modelling responsiveness we have attempted to address the question of the sensitivity of the point of product differentiation depending on what the priorities of a supply chain manager are with respect to reducing inventory costs and improving responsiveness.

2.2 Total cost expression for a serial supply chain stage

In this sub-section for the sake of the continuity and to facilitate the understanding of our specific contribution in this paper as presented in Sub-sections 2.3–2.5 and Sections 3–5, we present the total cost expression for a serial supply chain stage (building block) developed by Vanteddu, Chinnam, and Gusikhin (2011) along with the explanation of the different terms therein in a summary fashion. In this context, it needs to be understood that the building block-based approach has been used to address an entirely different research question in this research and consequently all the relevant theoretical analyses (Sub-sections 2.3–2.5), examples (Sections 3 and 5) and results (Section 4) are unique. Readers are encouraged to refer to Vanteddu, Chinnam, and Gusikhin (2011) for a detailed description of the model and the relevant assumptions.

Total cost expression for a serial supply stage presented by Vanteddu, Chinnam, and Gusikhin (2011) extends the work of Graves and Willems (2003) for a stochastic service model in supply chains by considering both inventory and responsiveness related costs. In a stochastic service model (Lee and Billington 1993; Ettl et al. 2000; Graves and Willems 2003; Simchi-Levi and Zhao 2005), delivery time between stages is variable depending on the availability of material and each stage follows a base stock policy.

Total inventory and responsiveness related cost at stage \( j \) as given by Vanteddu, Chinnam, and Gusikhin (2011) is as follows.

\[ TC_j = C_{j}^{SSC} + TRC_j + WIP_j + RWIP_j \]  

(1)

A brief description of the different terms of Equation (1) is presented below.

\[ C_{j}^{SSC} \]: Total Safety stock holding cost at stage \( j \) per period;

\[ C_{j}^{SSC} = C_j h_j E[SS_j] \]  

(2)

Expected safety stock at stage \( j \), \( E[SS_j] \) by given;

\[ E[SS_j] = \sigma_w \left( k_j + \int_{z=k_j}^{\infty} (z-k_j) \phi(z) dz \right) \]  

(3)

\( \sigma_w \) = Standard deviation of the demand during replenishment period \( W_j \) for stage \( j \);

\[ \sigma_w = \sqrt{\sigma^2 E[\gamma_j] + (\sigma_j^2) \mu^2} \]  

(4)

Equation (4) accounts for both the lead time variability at stage \( j \) and the portion of the lead time variability transferred from the preceding stage (see e.g. Feller 1960; Eppen and Martin 1988).

Demand at stage \( j \) is assumed to be \( N(\mu, \sigma^2) \);

\( E[\gamma_j] \): expected replenishment cycle time at stage \( j \);

\[ E[\gamma_j] = (L_j + (1 - \Phi(k_j))L_i)c_j \]  

(5)

Processing time at stage \( j \), \( \tau_j \sim N(L_j, \sigma_j^2) \); \( \pi_j = 1 - \Phi(k_j) \), the probability of stock out at the preceding stage \( i \);

\( c_j \): Coefficient of inverse responsiveness at stage \( j \) is defined as the ratio of the average demand to the rate of production (throughput) \( p_j \);

\[ c_j = \mu / p_j \]  

(6)

\( c_j \) is assumed to be less than or equal to 1, meaning that there is enough capacity at all the stages to satisfy a given demand. The introduction of ‘coefficient of inverse responsiveness (CIR)’ facilitates the simultaneous incorporation of SC responsiveness costs along with holding costs into the model. Simply put, keeping the average cycle stock constant, as the value of CIR goes down (moves away from ‘1’ toward ‘0’) at a given stage, relevant stage’s average
replenishment cycle time goes down, which causes the responsiveness to go up and vice versa, hence the name ‘coefficient of inverse responsiveness’.

Variance of the replenishment cycle time at stage \( j \) is given by \( \sigma_{rj}^2 \):

\[
\sigma_{rj}^2 = \left( \sigma_j^2 + \sigma_l^2 (1 - \Phi(k_i)) \right) c_j
\]

(7)

\( k_j \): Safety factor to achieve the service level target \( \Phi(k_i) \) for stage \( j \).
\( \int_{x=-k}^{\infty} (z - k_j) \phi(z) dz \): Backorder safety factor (Ettl et al. 2000; Graves and Willems 2003).
\( C_j \) = Nominal cumulative cost of the product realised when \( c_j = 1 \), and \( h_j \) is the holding cost rate per period.

\( TRC_j \): Total responsiveness related cost at stage \( j \).

\[
TRC_j = DRC_j + IRC_j
\]

(8)

Direct responsiveness related costs at stage \( j \), \( DRC_j \) per period are incurred on account of operating at a higher processing speed to lower the average replenishment cycle time to meet the relevant responsiveness related goals (primarily represents increased investments in 5M resources namely, men, machine, material, method and measurement to improve the flexibility at a stage).

\[
DRC_j = [f(1-c_j)](C_j - C_i)\mu
\]

(9)

\( f(1-c_j) \) represents cost of volume flexibility function at stage \( j \);
\( IRC_j \) represents indirect responsiveness related costs at stage \( j \) due to increased safety stock costs on account of operating at a higher processing speed (i.e. lower \( c_j \) value).

\[
IRC_j = [f(1-c_j)](C_j - C_i)c_jE[SS_j]
\]

(10)

\( WIP_j \) at stage \( j \) represents average cycle stock cost per period;

\[
WIP_j = ((C_j + C_i)/2)h_j\mu (L_j + (1 - \Phi(k_i))L_i)
\]

(11)

Responsiveness related cycle stock cost at stage \( j \), \( RWIP_j \) is assumed to increase the average cycle stock cost differential between stages \( j \& i \) by a value, assumed to be a function of \( (1-c_j)\&(1-c_i) \).

\[
RWIP_j = [f((1-c_j), (1-c_i))][(C_j - C_i)/2]h_j\mu (L_j + (1 - \Phi(k_i))L_i)
\]

(12)

### 2.3 Safety stock costs at unique and common component stages

We assume there are two final products and the demands are independent, identical and normal for both the products. This assumption is reasonable, as long as the target customers for the products (say, value vs. luxury versions) are reasonably distinct. If the assumption of independence cannot be reasonably satisfied, relevant covariance between demand variables need to be factored into the model. Form postponement is commonly regarded as an approach to mass customisation (Skipworth and Harrison 2006), which we assume for our model. Also, at any point of time, we are not considering multiple points of differentiation. We also assume that standardisation is the approach adopted for postponement. Standardisation and modular design enable a firm to configure a large number of different end products from a limited set of standard components, typically by combining a limited number of core modules with an array of modules that provide different levels of functionality (Ulrich 1995; Lee and Tang 1997). A major benefit of postponement in the supply chain relates to inventory reduction and service improvement, because holding inventory of a non-specific product requires less safety stock compared to holding inventory of several specific products (Aviv and Federgruen 2001).

Let us assume that postponement is considered at stage \( j \) in a serial supply chain architecture with opportunity to produce common components at stage \( j \) for two different products 1 and 2. Let us also assume that there are opportunities available to produce unique components specific to products 1 and 2 at stage \( j \), demands for which are assumed to be independent, identical and normally distributed. Let the corresponding stages involved in the production of unique components specific to products 1 and 2 be represented by stages \( j_1 \) and \( j_2 \). For the sake of simplicity, prior to stage \( j \), we assume that product differentiation is not possible. Or in other words, option for either differentiating (into two different products) or postponing is available only from stage \( j \).

**Product 1 demand:** \( N(\mu_1, \sigma_1^2) \)

**Product 2 demand:** \( N(\mu_2, \sigma_2^2) \)
Using the same notation as presented in Sub-section 2.2, safety stock costs at unique component stages $j_1$ and $j_2$ are given by (from Equation (2));

$$C_{j_1}^{SSC} = C_{j_1} h_{j_1} \sqrt{\sigma_1^2 E_{SS_{j_1}}} + (\sigma_1^2 + \mu_1^2) \left( k_{j_1} + \int_{z=k_{j_1}}^{\infty} (z-k_{j_1}) \phi(z) dz \right)$$

(13)

$$C_{j_2}^{SSC} = C_{j_2} h_{j_2} \sqrt{\sigma_2^2 E_{SS_{j_2}}} + (\sigma_2^2 + \mu_2^2) \left( k_{j_2} + \int_{z=k_{j_2}}^{\infty} (z-k_{j_2}) \phi(z) dz \right)$$

(14)

Safety stock cost at common component stage $j$ is given by

$$C_{j}^{SSC} = C_{j} h_{j} \sqrt{\left( \sigma_1^2 + \sigma_2^2 \right) E_{SS_{j}}} + (\sigma_1^2 + \sigma_2^2 + \mu_1^2 + \mu_2^2) \left( k_{j} + \int_{z=k_{j}}^{\infty} (z-k_{j}) \phi(z) dz \right)$$

(15)

Based on Equations (2), (8–10), total safety stock costs in the presence of increase in costs at stages $j_1$ and $j_2$ that account for the increase in the responsiveness, per period are given as follows.

$$C_{j_1}^{TSC} = C_{j_1}^{SSC} + [f(1-c_{j_1})](C_{j_1} - C_i) \mu_1 + [f(1-c_{j_1})](C_{j_1} - C_i) h_j E(SS_{j_1})$$

(16)

$$C_{j_2}^{TSC} = C_{j_2}^{SSC} + [f(1-c_{j_2})](C_{j_2} - C_i) \mu_2 + [f(1-c_{j_2})](C_{j_2} - C_i) h_j E(SS_{j_2})$$

(17)

Likewise, total safety stock costs in the presence of increase in costs at common component stage $j$ that accounts for the increase in the responsiveness, per period is given by

$$C_{j}^{TSC} = C_{j}^{SSC} + [f(1-c_{j})](C_{j} - C_i) (\mu_1 + \mu_2) + [f(1-c_{j})](C_{j} - C_i) h_j E(SS_{j})$$

(18)

### 2.4 Cycle stock costs at unique and common component stages

Average cycle stock costs at unique component stages $j_1$ and $j_2$ per period are given as follows.

$$WIP_{j_1} = ((C_{j_1} + C_i)/2) h_{j_1} t_{j_1} (L_{j_1} + (1 - \Phi(k_{j_1}))L_i)$$

(19)

$$WIP_{j_2} = ((C_{j_2} + C_i)/2) h_{j_2} t_{j_2} (L_{j_2} + (1 - \Phi(k_{j_2}))L_i)$$

(20)

Likewise, average cycle stock cost at common component stage $j$ per period is given as follows.

$$WIP_{j} = ((C_{j} + C_i)/2) h_{j} (\mu_1 + \mu_2) (L_j + (1 - \Phi(k_{j}))L_i)$$

(21)

Responsiveness related cycle stock Cost at stage $j_1$ is assumed to increase the difference of average cycle stock value at stages $j_1$ and $i$ by a value, which is a function of $(1 - c_{j_1})\&(1 - c_i)$.

$$RWIP_{j_1} = [f((1-c_{j_1}),(1-c_i))][(C_{j_1} - C_i)/2] h_j t_{j_1} (L_{j_1} + (1 - \Phi(k_{j_1}))L_i)$$

(22)

Likewise, responsiveness related cycle stock cost at stages $j_2$ is assumed to increase the difference of average cycle stock value at stages $j_2$ and $i$ by a value, which is a function of $(1 - c_{j_2})\&(1 - c_i)$.

$$RWIP_{j_2} = [f((1-c_{j_2}),(1-c_i))][(C_{j_2} - C_i)/2] h_j t_{j_2} (L_{j_2} + (1 - \Phi(k_{j_2}))L_i)$$

(23)

Responsiveness related cycle stock cost at common component stage $j$ is assumed to increase the difference of average cycle stock value at stages $j$ and $i$ by a value, which is a function of $(1 - c_{j})\&(1 - c_i)$.

$$RWIP_{j} = [f((1-c_{j}),(1-c_i))][(C_{j} - C_i)/2] h_{j} (\mu_1 + \mu_2) (L_j + (1 - \Phi(k_{j}))L_i)$$

(24)

### 2.5 Total inventory and responsiveness related costs at unique and common component stages

Therefore, total inventory and responsiveness related costs at unique component stages $j_1$ and $j_2$ per period are given as follows.
 Total inventory and responsiveness related cost at common component stage per period is given as follows.

\[
TC_j^{(\text{common})} = C_j^{TSC} + WIP_j + RWIP_j
\]

\[
TC_j = C_j^{TSC} + WIP_j + RWIP_j
\]

Cost savings on account of postponement compared to product differentiation at stage \( j \) is given by

\[
CS_j^{\text{Postponement}} = \frac{TC_j^{(\text{unique})}}{TC_j^{(\text{common})}}
\]

If \( CS_j^{\text{Postponement}} \) is a ‘positive’ quantity, postponement is advantageous at stage ‘\( j \)’ and if it is a ‘negative’ quantity, product differentiation is advantageous at stage ‘\( j \)’.

Because, ‘\( j \)’ is assumed to be the first stage, where in product differentiation/or postponement is possible, total supply chain cost savings \( CS_{POD=j} \), if any, if stage ‘\( j \)’ is made the POD compared to the option of ‘postponement’ for all the downstream stages starting from stage ‘\( j \)’, is given by

\[
CS_{POD=j} = \sum_{j=1}^{n} CS_j^{\text{Postponement}}
\]

Table 1. Key parameter values for postponement vs. differentiation options.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Common Harness</th>
<th>Luxury Model</th>
<th>Basic Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Facility</td>
<td>243</td>
<td>12</td>
<td>272</td>
</tr>
<tr>
<td>Remote Transport</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Mean Processing time (Days) ( L_j )</td>
<td>3</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Processing time SD (Days) ( \sigma_j )</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Inventory carrying cost per year % ( k_i )</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Mean Demand per day ( \mu )</td>
<td>800</td>
<td>800</td>
<td>200</td>
</tr>
<tr>
<td>Demand SD per day ( \sigma )</td>
<td>150</td>
<td>150</td>
<td>54</td>
</tr>
<tr>
<td>Safety Coefficient ( k_j )</td>
<td>1.28</td>
<td>1.28</td>
<td>1.28</td>
</tr>
<tr>
<td>Average back order coeff ( \pi_j )</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Service Level ( \Phi(k_j) )</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Therefore if,

\[ CS_{POD,j} < 0: \text{Product differentiation at stage } j \text{' is advantageous over postponement;} \]

\[ CS_{POD,j} > 0: \text{Postponement is advantageous over product differentiation at stage } j'; \]

\[ CS_{POD,j} = 0: \text{Because of the equivalence of costs, a supply chain manager will have the flexibility to make a} \]

decision taking into consideration other SC configuration related issues.

3. Illustrative example

In this section, we present an illustrative example focusing on the issue of the sensitivity of POD.

A wiring harness is designed to wire the vehicle and is one of the crucial purchased products for an automobile. It is a string of cables that transmit information signals to different points in an automobile that includes built-in fuses, relays for fans, pumps, auxiliary power etc. Harness has bundle identifiers for easy identification and installation to production sensors at the OEM facility.

Consider an OEM facility located in US Midwest and a supplier located in Southern states or across the border in Mexico (labelled as Remote), for wiring harnesses. Information for the key parameters is provided in Table 1. The primary purpose of this example is to aid a practitioner to make use of the model and to demonstrate the interplay of inventory and responsiveness cost elements in a typical real-world postponement context.

Remote supplier manufactures a common wiring harness that is differentiated into two different SKUs, one a luxury version and other basic version at the OEM facility. Total cost of $206,258 per day is incurred with common harness option. There is also flexibility at the remote facility to produce these two versions by making separate allocations in terms of manpower, machines etc., that is, differentiation of SKUs is possible at the supplier facility itself. The values of the parameters when differentiation is performed at the supplier facility are also provided in Table 1. The goal is to investigate whether postponement is advantageous in terms of the total cost.

Risk-pooling advantage due to postponement in terms of safety stock cost savings, because of pooled demand standard deviation is the only benefit considered. Under differentiation, luxury model costs more and basic model costs less compared to the postponement option with a common harness. Average price of a harness produced under differentiation option is approximately 7% cheaper than the one produced under postponement option. Unique harnesses tend to cost cheaper because of less complexity in operations particularly for the basic version that result in reduced quality related costs and allows for the use of relatively less skilled workforce. The analysis of the data using the cost model developed results in the following (Figure 1).

The safety stock cost advantage for postponement under cost parity with differentiation option due to risk pooling is $18 per day. As the supply chain becomes more responsive (coefficient of inverse responsiveness \( C_j \) moving toward ‘0’) mean processing time \( (L_j) \) and processing time SD \( (\sigma_j) \) in Table 1 also tend toward ‘0’; thereby effectively reducing the need for maintaining any safety stock i.e. $18 advantage for postponement under cost parity with differentiation will slowly approach ‘0’ making postponement not so attractive as the POD stage becomes less sensitive to the placement in the supply chain (related to managerial insight 1 in Section 4).

But under differentiation, average cost of the wiring harness is lower than under postponement (shown as ECC, which stands for expensive common component). This results in safety stock cost advantage of $29 per day and cycle stock cost advantage of $141 per day for the differentiation option. In addition, savings due to direct cost differential

\[ SS_{18}, \quad CS, 0 \]

\[ SS_{-29}, \quad CS, -141 \]

Figure 1. Postponement vs. differentiation.
are $14,800 per day for differentiation option. The total costs for differentiation option turn out to be $191,288 per day compared to the total cost with postponement of $206,258 per day. Also, if improved inventory parameters are considered for differentiation option i.e. lower values of \( L_j, \sigma_j \) and \( h_j \) compared to postponement option, safety stock cost advantage will be more than $29 per day and cycle stock cost advantage will be more than $141 per day further bringing down the total cost of differentiation from the current value of $191,288 per day. As the supply chain becomes more responsive, the advantage for the differentiation option will be further accentuated as explained in the previous paragraph (related to managerial insight 2 in Section 4).

It can also be noted that cheaper unique components or better inventory parameters at downstream unique stages, e.g. either at ‘Remote Transport’ stage or later compared to upstream stages such as ‘Remote Facility’ or before will result in larger savings on account of larger cumulative costs. For example, cumulative cost for the Basic model after the ‘Remote Facility’ stage is $203, whereas after the ‘Remote Transport’ stage it is $219. This in typical circumstances might result in shifting the POD downstream to take advantage of relatively larger inventory savings on account of larger cumulative costs compared to upstream stage location of the POD (related to managerial insight 3 in Section 4).

Inventory cost savings with differentiation are much smaller in magnitude in this case compared to direct cost differential, because just one stage (consisting of two sub stages) is considered. When you take into consideration complex supply chains with a large number of nodes there will be savings in safety stock costs and cycle stock costs even at the downstream stages on account of the lower cost structure for the differentiation option. In such a case, inventory savings will become significant and may even be comparable to savings due to direct cost differential. Even though in this case, savings due to direct cost differential are able to clearly offset the disadvantage due to disaggregation of the inventories that may not be case in complex supply chains, wherein the echelon inventory cost savings also play a key role.

4. Managerial insights

4.1 Managerial insight 1

Managerial insight 1: All other things being equal, least cost POD stage will become less sensitive to the placement in the supply chain as the supply chain focus shifts from cost to responsiveness.

Based on the total cost expressions (Equations (27) and (28) as appropriate for a given stage in a serial supply chain), all the other things being equal, in a typical context, total supply chain safety costs (Equations (16–18) as appropriate for a given stage) tend to be lower for a downstream stage point of differentiation relative to an upstream stage point of differentiation, especially when operating at; \( c_j = 1 \); such as for commodity products wherein cost would be the primary concern and one would not anticipate frequent changes of models that would necessitate operating at \( c_j \) values closer to ‘0’.

So, in such cases, \( CS_{POD=k} > CS_{POD=\ell} \), meaning that cost savings for a downstream stage ‘k’ will be larger relative to upstream stage ‘\( \ell \)’, and it would be better to shift the POD as close to the final customer as possible, which makes intuitive sense in line with the established results. But for products, where supply chain cycle time matters such as fast moving consumer goods etc., it becomes necessary to operate at \( c_j \) values closer to ‘0’. As the CIR value moves toward ‘0’, all the other things being equal, the difference between the total supply chain safety stock costs for stages ‘\( \ell \)’ and ‘k’ tend to diminish on account of the reduced replenishment lead time and the associated variability (Equations (16–18)), i.e. \( CS_{POD=k} - CS_{POD=\ell} \approx 0 \) as the CIR value moves toward ‘0’ from ‘1’.

It can also be seen from the discussion in the previous section that as the supply chain becomes more responsive, $18 advantage for postponement under cost parity with differentiation will slowly disappear making postponement not so attractive at the downstream stages resulting in the POD stage becoming less sensitive to the placement in the supply chain.

4.2 Managerial insight 2

Managerial insight 2: As the SC becomes more responsive, least cost POD is more likely to move to that U/S stage (which includes not resorting to postponement at all, when U/S stage is 1), where from, the effect of cheaper unique components, better inventory parameters etc. offsets the risk-pooling benefits of the other potential POD stages further downstream.

When we relax the cost parity assumption between ‘unique’ and ‘common’ components for the upstream stage ‘\( \ell \)’ relative to downstream stage ‘k’, in line with real-world experience, wherein ‘unique’ component cost typically tends to be relatively cheaper compared to ‘common’ component cost, cost savings if postponement is resorted to at stage ‘\( \ell \)’ (Equation (29)) will be diminished compared to cost parity case. For products, where supply chain cycle time
(responsiveness) matters such as electronic gadgets etc., it becomes necessary to operate at \( c_j \) values closer to '0', in which case, in addition to diminishing safety stock advantage for the downstream stage 'k', from managerial insight 1, the case for shifting the point of differentiation downstream will be further weakened on account of costlier common components.

Depending on the actual values of the parameters in a given context, it would be reasonable to assume that for some \( c_j \) value,

\[
CS_{POD=k} - CS_{POD=j} < 0;
\]

meaning that point of differentiation shifts upstream, that is, postponement may not be advantageous after all in such cases, which is counter intuitive in spirit to the generally agreed notions.

In place of cheaper unique components at upstream stage 'j', other mitigating factors such as relatively more efficient inventory parameters will also have a similar advantage compared to the downstream stage 'k', because of the increase in total supply chain costs and the reduction of safety stock cost advantage as the supply chain focus moves from cost to responsiveness (\( c_j \) moving toward '0').

We have seen through the illustrative example presented in the previous section that in the presence of cheaper unique components and/or improved inventory parameters for differentiation option, safety stock cost advantage will be at least $29 per day and cycle stock cost advantage will be at least $141 per day over the postponement option and the total cost of differentiation will be at most $191,288 per day compared to $206,258 per day total cost under postponement. As the supply chain more responsive, the advantage for the differentiation option will be further accentuated as explained in the previous section.

### 4.3 Managerial insight 3

**Managerial insight 3**: In a typical postponement scenario, for a given quantum of advantage in terms of cost, improved inventory parameters etc. at unique component manufacturing stages compared to the respective common component manufacturing stage, keeping all the other parameters constant, least cost POD will be biased towards downstream stages compared to upstream stages.

In cases, wherein options are available both at downstream stage 'k' and upstream stage 'j' for either reducing the cost of unique components or for improving the inventory parameters at unique component manufacturing facilities relative to common component manufacturing facility by a specified proportion, the relative cost savings at the downstream stage 'k' will be typically larger compared to upstream stage 'j';

\[
CS_{POD=k} - CS_{POD=j} > 0
\]

primarily on account of larger cumulative value of the product, which in turn will result in larger inventory carrying costs at downstream stages leading to differentiation more desirable at stage 'k' than at stage 'j', meaning that, it is preferable to postpone the differentiation of the product as close to the final customer as possible to take advantage of
cheaper unique components/ better inventory parameters at downstream stages relative to upstream stages with the same proportional advantage.

It can be seen from the illustrative example presented in the previous section that if the unique components were cheaper by the same 7% at an upstream stage (upstream of ‘Remote Facility’) the relevant safety stock cost advantage and cycle stock cost advantage compared to the postponement option are likely to be less than $29 per day and $141 per day, respectively on account of lower cumulative cost of the product at the upstream stage.

5. Model interpretation

5.1 Supply Chain focus-based location of the POD problem: (numerical analysis for management insight 1)

Numerical analyses performed in this section serve as an aid in explaining the managerial insights presented in Section 4. Parameter values used in the numerical analysis as presented in Table 2, are adopted from Vanteddu, Chinnam, and Gusikhin (2011), as this research builds upon the basic SC configuration framework presented in that paper. Configuration wise, a supply chain stage can be split to accommodate two or more products to facilitate the accommodation of relevant number of unique products at a given stage in the context of product postponement; whereas stage splitting is not allowed in Vanteddu, Chinnam, and Gusikhin (2011). Likewise, competing alternatives are considered at multiple stages for a given scenario in this research; whereas competing alternatives are considered at only one stage in Vanteddu, Chinnam, and Gusikhin (2011).

In this section, we focus on the optimal location of the POD as the supply chain focus moves on the cost-responsiveness spectrum. Let us consider a hypothetical supply chain as shown above (Figure 2) that delivers two different types of products 1 and 2. Let us also assume that there are opportunities to produce both the products by using common components at all the stages, that is, following the path 1-2-3-4-5. In this case, the common component at stage 5 will be differentiated into two different products after stage 5. Otherwise, we can choose to locate the POD either at stage 5, 4 or 3. For example, if POD is stage 4, product 1 will follow the path 1-2-3-41-51 and product 2 will follow the path 1-2-3-42-52. By considering each supply chain stage as a building block, we calculate inventory and responsiveness related costs (Equations (27) and (28)) both for postponement and differentiation to determine how the least cost POD is affected as the supply chain (SC) focus moves on the cost-responsiveness spectrum.

For this SC configuration framework, structural decisions are assumed to be already made and we also know the values of the parameters such as lead times, inventory carrying costs, etc. We are also assuming that the different stages are equivalent on other attributes, which are not considered explicitly in the model, such as quality etc.

For our numerical analysis, we have considered the parameter values as shown in Tables 2 and 3. Our primary focus is to analyse the cost advantage in terms of reduction in safety stock costs due to the risk-pooling effect by the use of common components. To isolate the advantages on account of the reduction in safety stocks, we have either not changed the values of the parameters for the stages manufacturing unique components for different points of differentiation or neutralised the effect of some parameters. For example, cost incurred at a stage, say stage 3, for producing a common component is considered equivalent to the cost incurred for producing unique components at stages 31 and 32. We are going to relax this assumption in Section 5.2 and study the effect of costly common components, which is usually the case, on the location of the POD.

Table 2. Typical values of the parameters adopted for this study (common components).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stage/player</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal cumulative cost $C_j$</td>
<td>106</td>
<td>150</td>
<td>240</td>
<td>472</td>
<td>1362</td>
<td></td>
</tr>
<tr>
<td>Mean Processing time (periods) $L_j$</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Demand variability $\sigma^2$</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Processing variability $(\mu^2\sigma_j^2)$ (in terms of number of units$^2$ of product)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Safety coefficient $k_j$</td>
<td>1.28</td>
<td>1.28</td>
<td>1.28</td>
<td>1.28</td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>Average back order coefficient $\pi_j$</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Average demand $\mu$</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Inventory holding cost $h_j$</td>
<td>0.017</td>
<td>0.017</td>
<td>0.017</td>
<td>0.017</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>Service level $\Phi(k_j)$</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>
In light of the values of the parameters chosen, it is not surprising that POD after stage 5 (POD A5) is the least cost option followed by POD 5, POD 4 and POD 3, respectively, because of the risk-pooling effect. As POD moves from stage 5 to 3, risk-pooling effect diminishes progressively compared to POD A5. But, the most important feature of Figure 3 is that the cost difference between POD A5 and POD 3, considered for the sake of better contrast, they being the cheapest and the costliest options, is progressively decreasing as the SC focus shifts from cost to responsiveness. As the CIR moves from 0.99 to 0.9, the cost difference between POD A5 and POD 3 has shrunk by around 5% and the difference will shrink by 36% for a CIR value of 0.3. As we have considered only safety stock-related benefits of the postponement for our analysis, the coefficient of \( r^2 \) in the safety stock cost expression and the responsiveness related safety stock cost expression gets progressively reduced along with CIR; thereby diminishing the benefit of risk pooling, resulting in making the postponement option unattractive. This analysis shows that as the emphasis shifts to SC responsiveness as the order winner in place of cost, the advantage of postponement due to risk pooling progressively decreases.

This is consistent with the mathematical requirement; \( CS_{POD=j} > 0 \) for postponement to be beneficial at any stage \( j \) from Section 2. As a supply chain becomes more responsive (coefficient of responsiveness moving towards ‘0’), average replenishment lead-time for the supply chain decreases (along with the associated variability), thereby reducing the necessity for maintaining large amounts of safety stock, which in turn impacts the advantage of postponement. This in turn, all the other things being equal, increases the \( TC_j(\text{common}) \) (total cost when postponed) relative to \( TC_j(\text{unique}) \) in Equation (29); thereby bringing \( CS_{POD=j} \) value closer to ‘0’.

In other words, least cost POD stage (the supply chain stage at which product differentiation is allowed [3, 4 and 5 in our case], that results in the least total cost for SC for a given priority attached to responsiveness through CIR value) will not be partial to downstream stages for its location, (which would be the usual case if there are considerable savings through the reduction in safety stock costs) compared to upstream stages, as the priority attached to responsiveness increases (decreasing CIR); thereby validating managerial insight 1 in typical postponement contexts.
Effect of the cost differential between common and unique components: (numerical analysis for management insights 2 and 3)

Hillier (2000) notes that if the common component is no more expensive than the one it replaces it is always worthwhile to use it. Though this is confirmed by Figure 3, we have seen that postponement loses its appeal as the SC focus shifts to responsiveness end of the spectrum under certain conditions. In our analysis, on the lines of Eynan and Rosenblatt (1996) and Hillier (2000), we relax the assumption that the cost of each of the replaced component is equal to the cost of the replacing common component. When compared to the assumption that the common (replacing) component cost was equal to those it replaces (see Baker 1985; Gerchak, Magazine, and Gamble 1988), the assumption that common component is costlier than the unique components is more realistic because a more ‘general purpose’ component typically costs more.

For our numerical analysis, we have considered nominal processing cost added at stages (31, 32), (41, 42) and (51, 52) that produce unique components to be 10% less than the respective common component costs at stages 3, 4 and 5, respectively. Common components are considered to be expensive one stage at a time. Figure 4 considers expensive common components only at stage 5 (ECC 5), Figure 5 considers expensive common components only at stage 4 (ECC 4) and Figure 6 considers expensive common components only at stage 3 (ECC 3). Rest of the values of the parameters remain the same as in Tables 2 and 3. It is clear from Figures 4, 4(A) and 4(B) that even though POD A5 is the least cost option in the beginning, POD 5 overtakes POD A5 in terms of least total cost at a CIR value of 0.95 and even POD 4 overtakes POD A5 at a CIR value close to 0.88. The shrinkage of the advantage of the postponement as was evident from Figure 3 is accentuated by the reduction in safety stock costs, direct responsiveness costs, cycle stock costs and responsiveness related cycle stock costs for POD 4 and POD 5 on account of lower unique component costs at stage 5, because both ‘cost added’ and ‘cumulative cost’ at stages 51 and 52 are reduced. Even if the responsiveness related safety stock costs are increasing in a specific context that cost component will be typically dominated by the much larger reductions in other aforementioned cost components. POD 4 is overtaking POD A5 slightly at a lower CIR value because it had to contend with additional safety stock costs on account of product differentiation occurring at stage 4. Because of the cost differential between the common and unique components, below the CIR value of 0.95 it is no longer advantageous to postpone the products until after stage 5, but it is cost effective to differentiate at stage 5, that is, optimal POD is moving upstream. Therefore, as the supply chain focus shifts to responsiveness, optimal POD
Figure 5. Effect of the cost differential on POD – (2). (A) Detail for the CIR range (0.93–1), (B) Detail for the CIR range (0.7–0.8).

Figure 6. Effect of the cost differential on POD – (3).
starting with POD A5 as optimal, which is the case when \( CIR = 1 \) becomes sensitive to the price differential at a particular stage and will move U/S at an appropriate value of \( CIR \), when the risk-pooling advantage is offset due to
(a) The reduction in processing time and the associated variability with decreasing \( CIR \) (as is clear from Figure 3).
(b) The reduction in direct and indirect safety stock costs, direct responsiveness costs, cycle stock costs and responsiveness related cycle stock costs on account of the cheaper unique components; thereby validating managerial insight 2 in typical postponement contexts.

In Figure 5, common component at stage 4 is considered to be expensive (by 10%) compared to unique components (ECC 4). Rest of the parameters remain the same from Tables 2 and 3. From Figures 5, 5(A) and 5(B) it is clear that POD A5 is the optimal POD for the whole range of \( CIRs \) considered. Here when POD is at stage 4, the additional advantage in terms of cheaper unique components is unable to offset the risk-pooling advantages when compared to POD A5, even though cost differential between POD A5 and POD 4 is reduced significantly compared to Figure 3. POD 3 fares much worse compared to POD 4 because of the lack of risk pooling even at stage 3.

In Figure 6, common component at stage 3 is considered to be expensive (by 10%) compared to unique components (ECC 3). Rest of the parameters remain the same from Tables 2 and 3. Here, POD A5 is the optimal POD for the whole range of \( CIRs \) considered. Here when POD is at stage 3, the additional advantage in terms of cheaper unique components is unable to offset the risk-pooling advantages when compared to POD A5, even though cost differential between POD A5 and POD 3 is reduced significantly compared to Figure 3.

In both the above cases, POD A5 continues to be optimal, when compared to the case in Figure 4 (ECC 5) because;
(a) For the same amount of decrease in the cost of unique component (we considered 10% decrease in all the three cases) the effect is much more at D/S stage PODs, because of the relatively larger nominal cost added, which is typically true for products for which postponement is suitable. Even if cost parity is assumed on that account, U/S stages as a POD will be relatively less favoured for the following reason.
(b) As the POD moves U/S, the advantages of the risk-pooling effect get progressively reduced. The only exception is when the effect of reduced cumulative costs at an U/S stage on the safety and cycle stock costs from that stage onwards (until the customer), on account of cheaper unique components, overrules the risk-pooling benefits.

Hence, for the same percentage of cost differential, in typical circumstances, POD location at D/S stages would be advantageous compared to U/S stages; thereby validating managerial insight 3 in typical postponement contexts.

5.3 Effect of efficient inventory parameters: (numerical analysis for management insights 2 and 3)

In this section, we are going to look at the effect of inventory parameters at different stages on the optimal location of the POD. The presence of better inventory parameters at the common component stages will always bolster the case of postponement, given that the other parameters are equivalent. Here, we particularly investigate the issue of unique component stages with better inventory parameters. The values of the inventory parameters given in Table 4 are adopted for the respective unique component stages compared to the values presented in Table 3.

The modified inventory parameters are adopted one stage at a time as we did in the earlier analysis. Remaining parameters were held constant. Here, again the risk-pooling benefit is in terms of safety stock cost savings only.

In Figure 7, when efficient inventory parameters are adopted at stages 51 and 52, it is denoted by EIP 5. From Figure 7, it is clear that POD A5 is the costliest option among all the possible POD stages. POD 5 is the least cost POD over the entire range of \( CIR \) followed by stages 4 and 3, respectively. When stage 5 is the POD, the effect of reduced average processing time, processing time variability and the inventory holding cost at stages 51 and 52 reduces the direct and indirect (responsiveness related) safety stock costs and cycle stock costs compared to the case presented in Figure 3 and the reduction is more than the corresponding risk-pooling benefit at any \( CIR \) value. The reduction also

| Table 4. Inventory parameters adopted for unique component stages. |
|---------------------------------|----------------|----------------|----------------|
| Unique component stages         | 31 & 32        | 41 & 42        | 51 & 52        |
| Avg processing time             | 0.98           | 0.98           | 0.98           |
| Processing time variability     | 6% less        | 6% less        | 6% less        |
| \( h \)                         | 0.015          | 0.015          | 0.015          |
overtakes additional safety stock costs, when POD moves to stages 4 and 3; thereby making stages 4 and 3 less costlier than POD A5 option. As the SC focus shifts to responsiveness this trend will be accentuated owing to the fixed reduction in cycle stock costs and the rapidly decreasing (depends on the nature of cost of volume flexibility function) responsiveness related cycle stock costs and relatively larger reduction in safety stock costs compared to Figure 3.

POD 3 and 4 are costlier than POD 5 because of the additional safety stock costs at those stages. On lines of the analysis performed in 5.2, this analysis shows that the presence of unique component manufacturing stages with efficient inventory parameters waters down the benefits of postponement and moves the least cost POD upstream; thereby validating managerial insight 2 in typical postponement contexts.

In Figure 8, unique component stages 41 and 42 are considered to have efficient inventory parameters (EIP 4). Rest of the parameters remain the same from Tables 2 and 3. Here, POD A5 is the optimal POD for the whole range of CIRs considered. Here when POD is at stage 4, the additional advantage in terms of better inventory parameters is unable to offset the risk-pooling advantages when compared to POD A5, even though cost differential between POD A5 and POD 4 is reduced significantly compared to Figure 3. POD 3 fares much worse compared to POD 4 because of the lack of risk pooling even at stage 3.

Figure 7. Effect of efficient inventory parameters on POD – (1).

Figure 8. Effect of efficient inventory parameters on POD – (2). (A) Detail for the CIR range (0.93–1). (B) Detail for the CIR range (0.9–0.93).
In Figure 9, unique component stages 31 and 32 are considered to have efficient inventory parameters (EIP 3). Rest of the parameters remain the same from Tables 2 and 3. Here, POD A5 is the optimal POD for the whole range of CIRs considered. Here when POD is at stage 3, the additional advantage in terms of cheaper inventory parameters is unable to offset the risk-pooling advantages when compared to POD A5, even though cost differential between POD A5 and POD 3 is reduced significantly compared to Figure 3. In both the above cases, POD A5 continues to be optimal, when compared to the case in Figure 7 for the same reasons, which were offered at the end of Section 5.2. Based on the analysis offered in this section, it is also seen that, least cost POD stage (the supply chain stage at which product differentiation is allowed (3, 4 and 5 in our case), that results in the least total cost for SC for a given priority attached to responsiveness through CIR value) will be partial toward downstream stages for its location compared to upstream stages for a given advantage such as unique components costing less by certain amount, processing time less by certain percentage etc., because relative savings in inventory holding costs tend to be larger for downstream stages on account of typically larger cumulative costs and also the safety stock cost savings tend to be larger on account of delayed differentiation for downstream stages; thereby validating managerial insight 3 in typical postponement contexts.

6. Conclusions

In present day competitive, globalised markets with shorter product life cycles there is a need to reduce the costs and the supply chain cycle time. In this paper, we present and analyse a strategic supply chain model to address the issue of the sensitivity of the optimal location of the POD in a supply chain by considering inventory costs and the responsiveness related costs assuming that the structural decisions are already made with respect to the supply chain network, that is, we develop the model as a supply chain configuration problem. We also offer context-specific counter-intuitive managerial insights in regards to the location of the POD in a serial supply chain. One of the novelties of this paper is that in addition to the traditional inventory costs, we have incorporated the supply chain responsiveness related costs into the model that allows for effective supply chain management with respect to these two critical order-winners simultaneously. We make use of a novel parameter called coefficient of responsiveness (CIR) to model responsiveness related costs at a stage, which also enhances the scalability of the model. In an optimisation context, the developed cost function for the ‘building block’ could be adopted for any type of supply chain network to aid in locating the optimal point of differentiation. Contrary to the generally agreed upon notions in the context of postponement, we establish that the location of the POD at upstream stages/ or not resorting to postponement at all may be the best strategy under certain circumstances as the SC focus shifts towards responsiveness.

We have considered only inventory related benefits with postponement but other aspects such as short and reliable delivery lead times, reduced repair and maintenance costs, design and development costs etc. are not addressed explicitly. Addition of these features will affect the POD location and will make the model more realistic. Organisational readiness, process type, operations scheduling etc., are some of the factors which play an important role in the successful implementation of the postponement strategy, the addition of which will enhance the applicability of the model.

Consideration of market structures and associated competition among different supply chains would be a new direction to extend the work presented here. Extent of information penetration and the degree of information symmetry are important issues in supply chain management that affect the sensitivity of the location of the POD, and their explicit consideration is also a potential area for possible extension of this research.
References


