

**Product Design from a  
Supply Chain Management  
Perspective**

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# **Product Design from a Supply Chain Management Perspective**

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The linkages between supply chain related issues and product design issues have not received much attention in literature. This paper presents a framework for supply chain strategy that integrates product design related cost and inventory costs. Postponement concept is an important supply chain strategy employed by firms to reduce inventory costs and lead-times, and to improve customer service levels. The postponement strategy is in the focus of research in the last few years and its importance is traced to the increasing trends in globalisation and product customisation. Exploitation of product modularity is an important element in the success of the postponement strategy. This paper builds on the existing concept of parts commonality index and introduces a new measure called Modularity Index, which is more comprehensive in nature.

*(Product Modularity, Product Design, Supply Chain Management, Postponement Strategy)*

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## 1. Introduction

Across the liberalised business world, the recent years are seeing a marked shift towards customisation and globalisation. According to Lee and Billington<sup>1</sup>, need for high customisation and market place globalisation lead to increased proliferation of product variety. Increase in product proliferation leads to an exponential increase in forecast errors (over and under forecasts). The result is excess inventory for some products and product shortages for others. Also, under high pressure for customer service, many operations managers choose to simply stock as much finished goods as possible. Firms across the world have to meet the increased competition by offering high variety of products at lower costs, while delivering them quickly. This, in turn, transforms into a challenge of establishment and maintenance of effective and efficient material flows along product supply chains.

In recent times, academicians as well as practitioners are using supply chain management framework. Currently, much of the efforts by firms are focused on the finishing stages of the supply chain. These are the stages where each product takes its identity. These are also the stages closest to the customer. This paper considers two supply chain strategies - postponement and product re-design - that lead to improvement in performance measures like cost, delivery and flexibility.

Lee<sup>2</sup> defines postponement as the delaying of an operational process to a later point in the supply chain, thereby delaying the point of product differentiation. Davis<sup>3</sup> highlights the use of postponement strategy to reduce work-in-process (WIP) inventory and transportation costs. He points out that demand uncertainty resulting from forecast errors was a key source of inefficiency in a supply chain. Lee and Tang<sup>4</sup> developed a model to identify the point of operation at which product differentiation should take place. They used investment cost, lead-times, processing cost and inventory carrying cost as performance measures, for a given customer service level.

According to Baker, Magazine and Nuttle<sup>5</sup> as the commonality increases the common parts' inventory required to achieve a particular service level reduces. Guerrero<sup>6</sup>, Gerchak *et. al.*<sup>7</sup>, and Benton and Krajewski<sup>8</sup> have studied the impact of parts commonality on system performance. These works are based on a single echelon inventory system and attention is on understanding the impact on inventory carrying cost due to change in parts commonality. However, impact of parts commonality on inventory levels at other stages in the supply chain is not addressed. Lee and Billington<sup>9</sup> describe the concept of "Design for Supply Chain Management" with the case of Hewlett-Packard (HP). According to the authors, supply-chain performance can be greatly improved by concurrently redesigning a product and its production process. Delaying the differentiation of products during manufacturing, by localisation and use of common parts are among the options for design for supply chain management. Lee<sup>2</sup> argues for product/process redesigning to deal with the operational problems of product proliferation. The intention of redesigning is to gain control of inventory and customer

service for the product, and a key design concept in this direction is delayed product differentiation. He adds that parts commonality is a powerful tool to achieve delayed product differentiation. However, research so far has not considered the cost of product/process re-design effort while assessing the *net* gains due to inventory reduction.

The approaches for product re-design are:

- i) internally driven: firms that aim to maintaining their existing product range while decreasing the number of parts in the system (parts standardisation), and
- ii) market driven: firms that are planning to broaden their product range without drastically altering the parts used (product customisation)

Parts standardisation and product customisation are among the significant issues in the realm of product re-design. Lee and Tang<sup>4</sup> have considered postponement and product re-design (standardisation of components) as special approaches for delaying product differentiation. However, not much work has been reported on the impact of product re-design on the postponement decision - the objective of this paper.

In this paper, assembly of parts (components) into finished products is reckoned as the product differentiation operation. Postponement refers to delaying the assembly operation to regional stock points instead of carrying it out at the central factory premise. We define a conventional model as one where the product assembly (or product differentiation operation) is done at a central location. Material is stocked as finished products in the regional stock points. In the postponement model, material is stocked as parts instead of as products at the regional stock points. Arrival of customer orders triggers the product differentiation operation at the respective regional product assemblies.

The postponement strategy is modeled in §2. A measure for product modularity is introduced in §3. Impact of product modularity on postponement strategy is detailed in §4. The conclusions are described in §5.

## **2. The Postponement Strategy Model**

In this section, we describe the postponement model. A conventional model is also built in order to make the relative advantages and disadvantages of the postponement strategy clear. The motivation for modelling in this paper was provided by the implementation of postponement strategy by a paint manufacturer. The features and assumptions of both the models mentioned below are based on practices at this firm. Till a few years back, this firm used to prepare all the shades of its emulsion paint product line at its factories. The firm was convinced that offering a very broad range was essential for improving its market share in the emulsion paint product line. However, it found that preparing more than 200 shades in its factories and shifting them to the markets was a logistics nightmare. Preparation of an emulsion shade involved mixing of a base and pigments that provided

that particular colour. This operation is known as 'tinting'. The time involved in tinting was negligible in comparison to the shipping time to the regions. The firm postponed tinting to the regional stock points. As a result, logistics from factories to regional stock points narrowed to two bases and about ten pigments. The firm also benefitted from the various benefits of the postponement strategy, which have already been described in §1.

### ***Conventional Model:***

#### **Figure 1**

The conventional model for a two regions situation is shown in Figure 1. We define a conventional model as one where the product assembly is done at a central location. When an order arrives from the regional point, parts required for the products assembly are drawn from central parts inventory. The finished products are shipped to the respective regional stock points. Customer orders arrive at the regional stock points. Thus, the conventional model is a Made-To-Stock (MTS) system.

### ***Postponement Model:***

#### **Figure 2**

The postponement model for a two regions situation is shown in Figure 2. In the postponement model, material is stocked as parts at central location as well as the regional stock points. Customer order arrival triggers the assembly operation at the respective regional product assemblies. In the postponement model, parts are made to stock while products are assembled to order. As assembly time is negligible, there is no need to maintain products inventories at the regional stock points, in the postponement model.

Given above structure and the assumption that assembly lead-time is negligible, it is seen that among the two inventory echelons, only the costs related to regional stock point inventories differ between the two models. Material is stored as parts at the central point in both models and, hence, there will be no differences in level and value of average inventory if inventory review frequency is same.

As mentioned in §1, Lee and Tang<sup>4</sup> have considered investment cost, lead-time, processing cost and inventory carrying cost as performance measures. We assume that transition from conventional to postponement model will not change lead-times as well as the operational costs associated with assembly and shipping operations. The relevant performance measures are then investment cost and inventory carrying cost.

Let the firm, for which the conventional and postponement models are built, offer  $P$  products through  $R$  regional stock points. The product assembly of a particular product involves assembly of certain parts belonging to a family of  $Q$  members. For modelling convenience, it is assumed that if a

particular part is required for a certain product assembly, the requirement is always one per product, in all cases.

As already mentioned, customer orders arrive at the regional stock points. For each of the products  $p$ , where  $p = 1, 2, \dots, P$ , the demand per period in the  $r^{\text{th}}$  regional stock point, where  $r = 1, 2, \dots, R$ , is assumed to be an i.i.d. random variable that is normally distributed. The mean and standard deviation of per period demand for  $p^{\text{th}}$  product in  $r^{\text{th}}$  region are denoted by  $\mu_{pr}$  and  $\sigma_{pr}$ , respectively. The mean and standard deviation of per period dependent demand of  $q^{\text{th}}$  part, where  $q = 1, 2, \dots, Q$ , in the  $r^{\text{th}}$  region are denoted by  $\bar{\mu}_{qr}$  and  $\bar{\sigma}_{qr}$ , respectively.

Let  $c_q$  be the unit cost of the  $q^{\text{th}}$  part at the regional stock points. An indicator variable,  $y_{pq}$ , is used for denoting whether  $q^{\text{th}}$  part is required by  $p^{\text{th}}$  product. It takes a value of 'one' if  $q^{\text{th}}$  part is required by  $p^{\text{th}}$  product and a value of 'zero' if  $q^{\text{th}}$  part is not required by  $p^{\text{th}}$  product. Let  $b$  be the cost of assembling one product at the assembly. It is assumed to be same for all the products. Let  $C_p$  be the unit cost of the  $p^{\text{th}}$  product at the regional stock points. The unit cost of the  $p^{\text{th}}$  product at the regional stock points can then be expressed as  $C_p = \sum_q y_{pq} c_q + b$ .

Let  $F$  be the amortised investment cost per period owing to change from conventional model to postponement model. It could take positive or negative values. A positive value indicates a net investment owing to the change. A negative value indicates reduction in costs owing to the postponement strategy. Lee and Tang<sup>4</sup> cite reduction in overhead cost owing to adoption of postponement strategy as an example of  $F$  taking a negative value.

In both the models, a periodic review order-up-to-level inventory policy (refer Hadley and Whitin<sup>10</sup>) is followed. We assume that the inventory review is done every period and orders placed to the central warehouse accordingly. Let  $t$  periods be the lead-time for shipping material from central warehouse to the regional stock points. Let  $z$  be the safety factor associated with the service level of the regional stock points and  $h$  be the interest rate per period on unit capital invested in inventory. We also assume that service level at the regional stock points (customer fill-rate) is a market-driven performance measure. Hence,  $z$  can be looked at as a proxy for target service level that has to be same for both models. For the same reason, back-order or lost sales costs are not considered as they will be same for both models for a given target service level.

Let  $TCC$  and  $TCP$  be the per period total relevant costs for the conventional and postponement models, respectively.

$$TCC = h \left\{ \left( \frac{1}{2} + t \right) \sum_p C_p \sum_r \mu_{pr} + z \sqrt{1+t} \sum_p C_p \sum_r \sigma_{pr} \right\} \dots \dots \dots (1)$$

$$TCP = F + h \left\{ \left( \frac{1}{2} + t \right) \sum_q c_q \sum_r \bar{\mu}_{qr} + z \sqrt{1+t} \sum_q c_q \sum_r \bar{\sigma}_{qr} \right\} \dots \dots \dots (2)$$

In both the equations (1 and 2), the first term within brace brackets describes the sum of average values of regional stock point cyclic inventories and shipping in-transit inventories. The second term within brace brackets describes the average value of regional stock point safety stocks.

Based on definition of  $C_p$  (i.e.,  $C_p = \sum_q y_{pq} c_q + b$ ), the term  $\sum_p C_p \sum_r \mu_{pr}$  can be expressed as

$\sum_q c_q \sum_r \bar{\mu}_{qr} + b \sum_p \sum_r \mu_{pr}$ . Substituting this, we can express (2) as

$$TCP = TCC + F - h \left\{ b \left( \frac{1}{2} + t \right) \sum_p \sum_r \mu_{pr} + z \sqrt{1+t} \left( \sum_p C_p \sum_r \sigma_{pr} - \sum_q c_q \sum_r \bar{\sigma}_{qr} \right) \right\} \dots \dots (3)$$

The term  $\left( \sum_p C_p \sum_r \sigma_{pr} - \sum_q c_q \sum_r \bar{\sigma}_{qr} \right)$  is always non-negative\*. This term describes the reduction in value of safety stocks when postponement strategy is employed. Then, it can be seen from (3) that the postponement strategy draws benefits from reduction of inventory costs. If  $F$  is zero or negative, it is seen that  $TCP$  is always less than  $TCC$ . However, when  $F$  is positive, the choice of continuing with conventional system or switching to postponement strategy has to be made by evaluating the inventory costs savings against the amortised investment cost.

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\* Since the product demands are i.i.d.s;  $\sqrt{x_1^2 + x_2^2} \leq x_1 + x_2$ , for any real valued  $x_1$  and  $x_2$ ; and  $C_p = \sum_q y_{pq} c_q + b$ , it follows that  $\sum_q c_q \sum_r \bar{\sigma}_{qr} = \sum_q c_q \sum_r \sqrt{\sum_p y_{pq}^2 \sigma_{pr}^2} \leq \sum_q c_q \sum_r \sum_p y_{pq} \sigma_{pr} \leq \sum_p C_p \sum_r \sigma_{pr} - b \sum_p \sum_r \sigma_{pr}$ . Hence,  $\sum_q c_q \sum_r \bar{\sigma}_{qr}$  is never greater than  $\sum_p C_p \sum_r \sigma_{pr}$ .

### 3. Product Modularity and Modularity Index

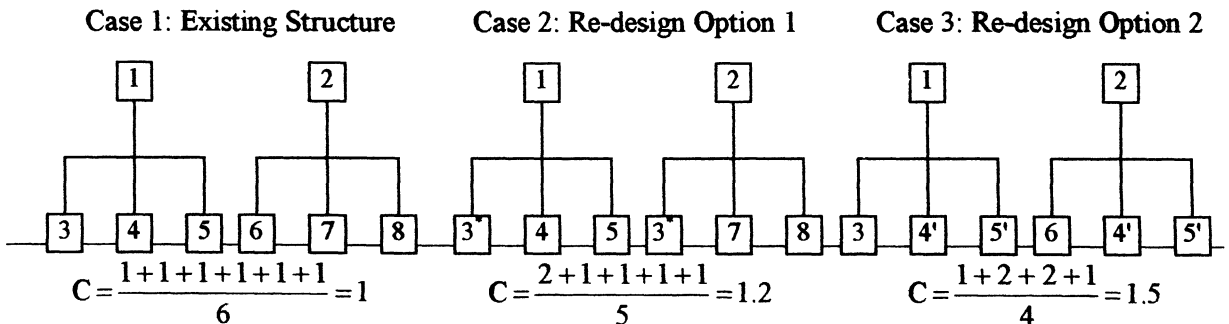
Equation (3) indicates that there are two dimensions to the savings in inventory carrying costs owing to postponement – value dimension and variability dimension. The value dimension refers to the reduction in inventory assets that results owing to value of parts being less than value of products (difference owing to value added in the assembly operation). All three types of inventories – regional stock points' cyclic inventories, shipping in-transit inventories and regional stock points' safety stocks – exhibit this reduction. The variability dimension refers to the reduction in inventory assets owing to variability reduction, which is caused by demand pooling effect of storing material as parts (variability reduction owing to parts commonality). This reduction is exhibited only by regional stock points' safety stocks.

The impact of parts commonality on inventory levels has been researched in recent times. Collier<sup>11</sup> defined the 'Degree of Commonality Index' as  $C = \frac{\sum_{j=1}^d \phi_j}{d}$ ,  $1 \leq C \leq \beta$ . Here,  $C$  is the degree of commonality index,  $\phi_j$  is the number of immediate parents component 'j' has over a set of end items or product structure level(s),  $d$  is the total number of distinct components in the set of end-items or product structure level(s) and  $\beta$  is the total number of immediate parents for all distinct component parts over a set of end-items or product structure level(s).

Collier's degree of commonality index suffers from two drawbacks:

- Collier's degree of commonality index captures the product structure related information but does not capture the effects of parts value and demand variability. As already mentioned, when material is stored as parts, commonality of parts results in demand variance pooling at that echelon. Hence, the safety stock requirement at that echelon reduces. This phenomenon cannot be understood clearly by using Collier's degree of commonality index.

In the example that follows, the firm offers two products 1 and 2. Case 1 refers to existing product structure. Product 1 requires one unit each of parts 3, 4 and 5. Product 2 requires one unit each of parts 6, 7 and 8. Case 2 refers to product structure when the firm decides to standardise one of the parts. In product 2, part 3 and part 6 are substituted by re-designed part 3 (denoted as part 3\*). Case 3 refers to product structure when the firm decides to standardise two of the three parts. In product 2, part 4 and part 7 are substituted by part 4', and part 5 and part 8 are substituted by part 5'.





We use a one regional stock point case to understand the impact of parts value and variability on Collier's degree of commonality index. Let product 1 and product 2 be offered to the market through the regional stock point. For this illustration we take that value addition in the assembly operation is zero. Using the notations employed in §2, the  $t$  and  $z$  values for this illustration are 3 periods and 2.0, respectively.

As value addition in the assembly operation is zero, total value of cyclic and shipping in-transit inventories are same irrespective of whether material is held as parts or products. Referring to Table 1, total value of cyclic and shipping in-transit inventories in all four cases (one products case and the 3 parts cases) are 75 and 450, respectively. The total value of safety stock inventories is 140.0 when material is held as products at the regional stock point. When material is held as parts in the regional stock point, the total value of safety stock inventories is 140, 108 and 132 for Case 1 ( $C = 1.0$ ), Case 2 ( $C = 1.2$ ) and Case 3 ( $C = 1.5$ ), respectively. Thus, this illustration shows that it is possible to obtain instances where inventory cost increases with Collier's degree of commonality index.

- b. Also Collier's degree of commonality index varies over the range 1 to  $\beta$ . As firm's product range changes, the scale used for measuring Collier's degree of commonality index also changes. This makes the value of Collier's degree of commonality index incomparable in cases of product range expansion.

An index, Modularity Index, which overcomes the drawbacks of Collier's degree of commonality index, is introduced. The Modularity Index is defined as the ratio of the value-weighted sum of standard deviations of regional product demands, of all products from all regions for a certain time duration, to the value-weighted sum of standard deviations of regional module demands, of all modules from all regions for the same time duration. Thus, in terms of the notations used in §2,

$$\text{Modularity Index, } M = \frac{\sum_p C_p \sum_r \sigma_{pr}}{\sum_q C_q \sum_r \bar{\sigma}_{qr}}, M \geq 1 \quad \dots \quad \dots \quad \dots \quad (4)$$

This index is the ratio of safety stocks when inventory is held as products instead of parts. For example, if  $M = 2$ , it means that to provide the same service level, safety stocks (in value terms) to be held as products will have to be twice as much as that to be held as parts. This reduction is owing to the value and variability dimensions that have been mentioned above. Using the definition as per

equation (4), it is seen that the  $M$  values for the three product structure cases in the above illustration are 1.000 (Case 1,  $C = 1.0$ ), 1.296 (Case 2,  $C = 1.2$ ) and 1.061 (Case 3,  $C = 1.5$ ), respectively.

We have already shown that inventory cost, in fact, may increase with increase in  $C$ . Thus, the impact of  $C$  on inventory cost is inconclusive. The modularity index,  $M$ , overcomes this shortcoming of Collier's index.

We had earlier mentioned part standardisation and product customisation approaches to product re-design. To our knowledge, there are no measures available in literature that can help firms in quantifying part standardisation and product customisation. To overcome this problem, we re-define part standardisation and product customisation, using concept of modularity index, as follows:

- i) **Parts Standardisation:** Increasing  $M$  value by decreasing the number of parts in the system while maintaining existing product range.
- ii) **Product Customisation:** Increasing  $M$  value by broadening the product range without altering the parts used.

In the next section, the notion of the modularity index is used to model the supply chain performance in the context of postponement strategy.

#### 4. Impact of Product Modularity on Postponement Strategy

Product modularity, as described in the previous section, can be effected through product re-design efforts. The objective of modelling in this section is to understand the behaviour of the total relevant cost for the different design options. This total relevant cost is the sum of costs that capture the re-design effort, parts costs and inventory costs. The postponement model in §2 includes only the amortised postponement specific cost and the inventory cost. In this section, the re-design related costs are added to earlier described postponement model.

Let a firm have  $N$  options of re-designing its existing products. Let  $M_n$  be the modularity index associated with the  $n^{\text{th}}$  design option. The difference in  $M_n$  for different design options is owing to choice of parts that are taken up for standardisation for the respective design option. It is assumed that the  $N$  design options are ordered in such a way that for  $n'' > n'$ ,  $M_{n''} > M_{n'}$ . In other words, the  $N$  design options are arranged in the increasing order of modularity index.

Consider the following notations for modelling the total relevant costs:

The index  $n$ ,  $n = 0, 1, \dots, N$ , is used to describe design options. Here,  $n = 0$  refers to the state prior to product re-design effort.

$\mu_{npr}$  – Mean of per period demand for  $p^{\text{th}}$  product in  $r^{\text{th}}$  region (in any period) when  $n^{\text{th}}$  option is employed

$\sigma_{npr}$  – Standard deviation of per period demand for  $p^{\text{th}}$  product in  $r^{\text{th}}$  region (in any period) when

$n^{\text{th}}$  option is employed per period

- $\bar{\mu}_{nqr}$  – Mean of per period dependent demand for  $q^{\text{th}}$  part in  $r^{\text{th}}$  region (in any period) when  $n^{\text{th}}$  option is employed
- $\bar{\sigma}_{nqr}$  – Standard deviation of per period dependent demand for  $q^{\text{th}}$  part in  $r^{\text{th}}$  region (in any period) when  $n^{\text{th}}$  option is employed
- $c_{nq}$  – Unit cost of  $q^{\text{th}}$  part at the regional stocking point when  $n^{\text{th}}$  option is employed
- $y_{npq}$  – Indicator variable, for denoting whether  $q^{\text{th}}$  part is required by  $p^{\text{th}}$  product when  $n^{\text{th}}$  option is employed, where

$y_{npq} = 0$  if  $p^{\text{th}}$  product does not require  $q^{\text{th}}$  part when  $n^{\text{th}}$  option is employed

$y_{npq} = 1$  if  $p^{\text{th}}$  product requires  $q^{\text{th}}$  part when  $n^{\text{th}}$  option is employed

- $C_{np}$  – Unit cost of  $p^{\text{th}}$  product at the regional stocking point when  $n^{\text{th}}$  option is employed, where

$$C_{np} = \sum_{q=1}^{Q_n} y_{npq} c_{nq} + b .$$

- $f_n$  – Amortised product re-design effort cost for  $n^{\text{th}}$  option, where  $f_0 = 0$  and  $f_n, n \neq 0 > 0$ .

The total relevant cost for the  $n^{\text{th}}$  design option is

$$TCP(n) = F + f_n + \sum_q c_{nq} \sum_r \bar{\mu}_{nqr} + b \sum_p \sum_r \mu_{npr} + h \left\{ \left( \frac{1}{2} + t \right) \sum_q c_{nq} \sum_r \bar{\mu}_{nqr} + z \sqrt{1+t} \sum_q c_{nq} \sum_r \bar{\sigma}_{nqr} \right\} \quad (5)$$

The optimal design option,  $n^* = \arg \min \{ TCP(n) : 0 \leq n \leq N \}$ .

$TCP(n)$  behaviour can be better understood by considering the implications of design options on following costs.

a) Re-design effort cost - Any design change will involve a one time cost, which will have to be amortised over the period of evaluation. In general, for any particular design option, re-design effort and corresponding modularity index are unrelated. It is possible to think of an option that will involve less re-design effort and will standardise parts that have high value and high demand variability, which will result in high modularity index. This in turn means that for  $n'' > n'$ ,  $f_{n''}$  could be less than or greater than  $f_{n'}$ .

b) Part cost - Increasing modularity index would involve standardisation of parts, i.e., the same component is used across several product lines. This is likely to result in increase in costs of parts that are standardised because the standardised part has to be designed for the application with the

most stringent demand (Ulrich<sup>12</sup>). In other words,  $\sum_q c_{nq} \sum_r \bar{\mu}_{nqr} \Big|_{n=0} > \sum_q c_{0q} \sum_r \bar{\mu}_{0qr}$ . However,

for  $n'' > n'$ , since the degree of over design is likely to be different in different design options, it is

not possible to comment on the relationship between  $\sum_q C_{n'q} \sum_r \bar{\mu}_{n'qr}$  and  $\sum_q C_{n''q} \sum_r \bar{\mu}_{n''qr}$ . Stated otherwise, the value of the parts consumed per period will increase owing to any of the re-design efforts. However, there is no relationship between this increase and increase in modularity design.

- c) **Regional stock point safety stock:** As mentioned above, for  $n'' > n'$ ,  $M_{n''} > M_{n'}$ . This means that for  $n'' > n'$ , the regional stock point safety stocks monotonically decreases with increase in  $n$ .

Because of the different behaviours of the above three costs with respect to  $n$ , conclusive generalisations of the total cost behaviour is not possible. This means that one has to consider the specific impacts of each of these three costs before deciding on optimal design option to be adopted.

Figure 3

In case of high valued parts and uncertain product demands, the total relevant cost of various designs is likely to behave as shown in Figure 3, as the safety stock costs are likely to be of much higher order than design related costs. Hence, the nature of the total relevant cost curve (AB), where point A represents the case of postponement strategy prior to any re-design effort ( $n = 0$ ) and point B represents the state of optimal design option ( $n = n^*$ ).

The horizontal dotted lines in Figure 3 represent three cases of the total relevant costs in conventional model.

*Case 1:* In this case, the total relevant cost reduces by a mere shift from conventional model to postponement strategy (point A). However, the total relevant cost can be further reduced through product re-design efforts.

*Case 2:* In this case, conventional model is preferable to postponement strategy without product re-design efforts. However, the postponement strategy becomes attractive with appropriate product re-design efforts.

*Case 3:* In this case, even with best product re-design effort, postponement strategy is not preferred to conventional model. This typically is the case when investment required for postponement is very high.

It is important to note from above three cases that its important to consider postponement strategy and product re-design efforts jointly rather than in isolation.

## 5. Conclusions

Any product re-design effort leads to a one-time re-design cost, change in unit component cost, and change in the value of safety stock. The traditional approach to product re-design effort has been myopic limiting its attention to at best the first two components of the cost. In the process, the re-design efforts are assessed in terms of parts commonality reflecting mere product structure information. However, this paper demonstrated that re-design efforts impact not only the one-time

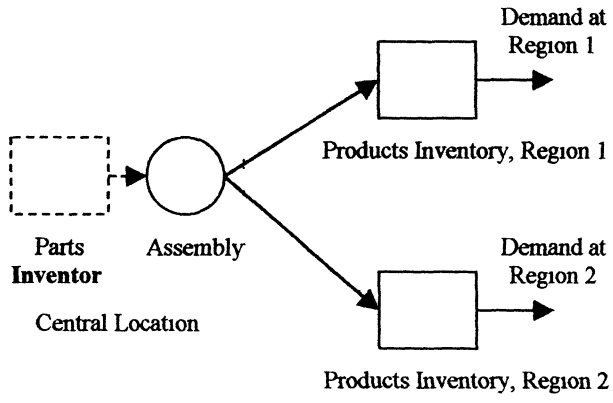
cost but also the value of stocks in the manufacturing system and also the safety stock levels in the distribution channel in case of postponement strategy. This has a significant implication to the practitioners - in that one has to take a more comprehensive view of the supply chain while deciding on the re-design efforts.

Further, product re-design is a significant issue particularly in case of high valued parts and/or high degree of demand uncertainty. A shift from no-postponement to postponement strategy can be made more attractive by appropriate product re-design (part standardization).

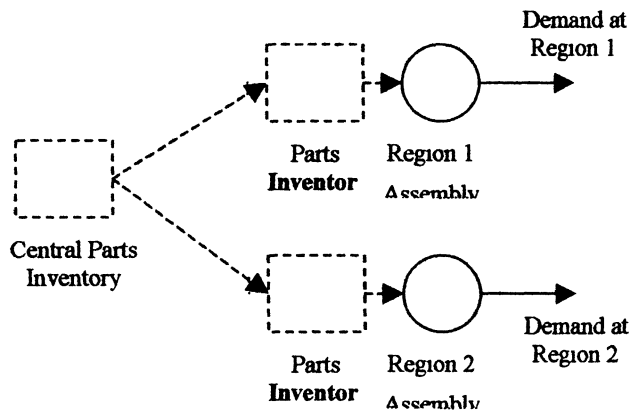
In the realm of research, the current method of measuring part commonality (Collier's  $C$ ) is shown to be myopic and of limited value. Modularity index ( $M$ ) - as introduced in this paper - is shown to be a better measure to identify areas for product re-design efforts. We have also shown how  $M$  can help firms in quantifying part standardisation and product customisation. It is true that  $M$  measures only the value dimension and variability dimension but does not capture the cost of design efforts. This calls for further work to refine the notion of modularity index to facilitate identification of avenues for design efforts better.

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**Figure 1: Conventional Model**

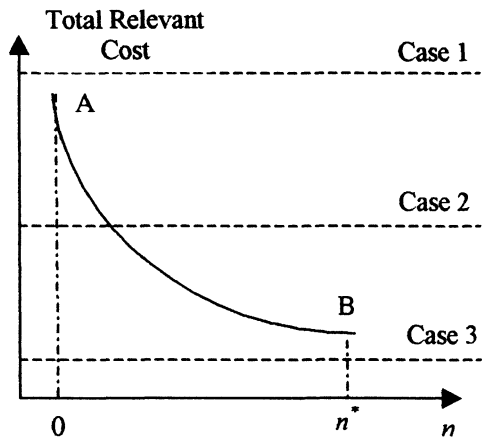


**Figure 2: Postponement Model**

**Table 1: Illustration of Parts Value and Variability Impact on Value of Inventories held**

	Demand		Cost	Value of average inventory held		
	Mean	Std. dev.		Cyclic	Shipping In-transit	Safety Stock
Product 1	100	20	1.0	50.0	300.0	80.0
Product 2	50	15	1.0	25.0	150.0	60.0
<b>Total</b>				75.0	450.0	140.0
Case 1: C = 1.0						
Part 3	100	20	0.8	40.0	240.0	64.0
Part 4	100	20	0.1	5.0	30.0	8.0
Part 5	100	20	0.1	5.0	30.0	8.0
Part 6	50	15	0.8	20.0	120.0	48.0
Part 7	50	15	0.1	2.5	15.0	6.0
Part 8	50	15	0.1	2.5	15.0	6.0
<b>Total</b>				75.0	450.0	140.0
Case 2: C = 1.2						
Part 3*	150	25	0.8	60.0	360.0	80.0
Part 4	100	20	0.1	5.0	30.0	8.0
Part 5	100	20	0.1	5.0	30.0	8.0
Part 7	50	15	0.1	2.5	15.0	6.0
Part 8	50	15	0.1	2.5	15.0	6.0
<b>Total</b>				75.0	450.0	108.0
Case 3: C = 1.5						
Part 3	100	20	0.8	40.0	240.0	64.0
Part 4'	150	25	0.1	7.5	45.0	10.0
Part 5'	150	25	0.1	7.5	45.0	10.0
Part 6	50	15	0.8	20.0	120.0	48.0
<b>Total</b>				75.0	450.0	132.0





**Figure 3: Total Relevant Cost for Design Options**