ANALYSIS OF POSTPONEMENT STRATEGIES IN SUPPLY CHAINS

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ABSTRACT
Inventory is an important part of supply chain management as it directly impacts both cost and service. As demand is more or less uncertain and it takes time to manufacture and deliver the goods, some amount of inventory is required somewhere in the chain to provide the required service to the end customer. Increasing supply chain inventories increases customer service and consequently the revenue, but it comes at a higher cost. The aim of supply chain inventory management is to optimize the inventories and to shift the current customer service curve outward through improved inventory strategies and redesigning the supply chain. This article is aimed at studying the effectiveness of various factors in the supply chain environment with and without postponement strategies. Analysis of these factors enables a better understanding of the supply chains and will help to design these systems more effectively. Simulation models are developed using Arena and are used to capture the system dynamics with probability distribution which provides valuable insight into which variables are the most important and how variables interact. It also helps to capture the uncertainty and stochastic nature of the model. Two-level Fractional Factorial Experimental designs are used to study and analyze the performance of service and inventory levels and to determine which variables are the most influential.

Keywords: Postponement Strategies, Supply Chain Networks, Inventory Management, Simulation

TEDARİK ZİNCİRLERİNDE ERTELEME STRATEJİLERİNİN ANALİZİ

ÖZET
Envanter hem maliyeti hem de servis kalitesini doğrudan etkilediğinden tedarik zinciri yönetiminin önemli bir parçasını oluşturur. Talep bir ölçűde belirsiz olduğu ve űrűnlerin űretimi ve teslimi belli bir zaman aldığı için, tedarik zincirinde bir miktar envanter bulundurmak műşteriye gerekli servisi verebilmek için gereklidir. Tedarik zincirindeki envanteri artırmak műşteri hizmetini artırarak sonunda gelirleri de artırır; ancak envanter daha bűyűk bir maliyet te gerektirir. Tedarik zinciri envanter yönetiminin amacı daha gelişmiş envanter stratejileri ve tedarik zincirinin yeniden tasarlanması yoluyla envanter miktarlarını ve műşteri hizmetleri eğrisini eniyilemektir. Bu makalenin amacı tedarik zinciri ortamında çeşitli faktörlerin ertelemenin olduğu veya olmadığı hallerde etkinliğini anlamaktır. Bu faktörlerin analizi bizim tedarik zincirlerini daha iyi anlamamızı ve bu sistemleri daha etkin bir sekilde tasarlamamızı sağlayacaktır. Arena yazılım programı kullanılarak geliştirilen ve sistem dinamiğini ve olasılık dağılımlarını modelleyen benzetim programı yoluyla hangi değişkenlerin önemli olduğu ve bu değişkenlerin aralarındaki etkileşimin nasıl olduğu yolunda daha iyi bir anlayışa sahip olunmuştur. İki seviyeli kısmi faktöriyel deney tasarımları kullanılarak servis ve envanter seviyelerinin performansı ve hangi değişkenlerin bu performans űzerinde en fazla etkili olduğu araştırılmıştır.

Anahtar Kelimeler: Erteleme Stratejileri, Tedearik Zinciri Ağları, Envanter Yönetimi, Benzetim

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1. INTRODUCTION

Over the past 10 years, there has been a growing consciousness in industry towards the importance of effective Supply Chain Management (SCM). The term supply chain has become a standard part of the business vocabulary. There are as many definitions for the term as articles or books on the topic. The general idea, however, is integration. Excellent performance can be achieved by taking an integrated view of all the activities required to convert raw materials into finished goods. The result of poor integration is inventory. Inventories are required to buffer the uncertainties and inefficiencies. Therefore, inventory has become a crucial part of supply chain management. The manufacturing world is facing the challenge of delivering what the customers want, when they want, while meeting the financial need to keep inventory levels down. Postponement, also known as delayed differentiation, is an "adaptive supply chain strategy that enables companies to dramatically reduce inventory while improving customer service" (Muzumdar et al., 2003). The concept is to delay the point of commitment of work-in-process inventory into a final product and, thereby, gain control of efficient asset utilization in a dynamic and uncertain environment. Nowadays, consumers are demanding higher levels of customization, yet are not willing to pay extra or wait longer. Product proliferation is a common challenge for firms providing customized products. Postponement can be used to cope with this challenge. In this article, we study the effectiveness of these strategies. Component commonality is one of the most popular supply chain strategies to tackle the challenges such as difficulties in estimating demand, controlling inventory, and providing high service levels for customers. It promotes using a common component to substitute a number of unique components in various products so that safety stocks can be reduced due to risk pooling.

Mass customization can be achieved by postponing the configuration of generic components into a wide variety of end products. In postponement a product is processed till it remains generic and the customization is delayed until demand is realized. A generic product offers more flexibility when demand is uncertain since it can be transformed into any final product. Instead of keeping high finished goods inventory or suffer stock outs which can result in lost sales or interrupt plant production schedules, the customization of the product can be delayed until customer orders arrive. Postponement concept of delaying the point of product differentiation has been found to be an effective strategy in product variety. Postponement delays product differentiation at a point closer to the customer. This involves designing and developing generic products that can be customized once the actual demand is known. It also involves the implementation of precise inventory approach to position inventory farther away from the customer while satisfying the service levels and reducing the inventory costs. Postponement lessens the forecasting horizon and thereby solves the uncertainty of end product demand (Whang and Lee, 1998). Also better inventory performance can be achieved by redesigning a product or its supply chain. To serve as an example, Lee and Billington (1993) describe postponement efforts in the distribution of computer printers of a well-known electronics manufacturer. The printer industry being highly competitive, the customers of the company's computer peripherals (dealers) wanted to carry as little inventory as possible; yet wanted high level of availability to the end-users. The distribution process was re-engineered to implement postponement. This effectively moved the point of differentiation to the regions (e.g. language-specific users' manuals, the type of AC plugs, voltage requirements of different regions, etc.). This was achieved by making changes to the product design. As a result of these changes, there were additional investments due to product redesign and enhancement to distribution center capabilities. However, this additional investment was balanced by the resulting inventory savings due to postponement.

2. LITERATURE REVIEW

The concept of postponing product differentiation beyond manufacturing has been discussed for over 50 years (Alderson, 1950; Bucklin, 1965). Alderson (1950) appears to be the first who coined the term postponement in marketing literature. Alderson held that "the most general method which can be applied in promoting the efficiency of a marketing system is the postponement of differentiation,…., postpone changes in form and identify to the latest possible point in the marketing flow; postpone change in the inventory location to the latest possible point in time". According to him this approach could reduce the amount of uncertainty related to marketing operations. Bucklin (1965) provide arguments as to how postponement would be difficult in manufacturing environment mainly operating on a make-to-stock basis. He argued that some unit in the chain would have to bear the risks associated with product variety, and postponement only helped in shifting this risk to some other partner in the chain. However, as companies started to shift from the traditional make-to-stock to make-to-order policy, postponement has become an attractive alternative. Zinn et al. (1988) describe different types of postponement that could be executed in the supply chain and this includes labeling, packaging, assembly, manufacturing (from postponement) and time postponement. Extending the ideas of Zinn et al. (1988), Pagh and Cooper (1998) developed a simple and conceptual model to explain the scope of postponement strategies that could be implemented by companies. Four generic strategies were identified: full speculation, logistics postponement, manufacturing postponement and full postponement.

Modeling postponement concept is similar to the modeling of a multi-echelon inventory system. In a multi-echelon system lower echelon are descendants of an upper echelon site. This is analogous to a postponement process in which multiple products share a common item. Eppen and Schrage (1981) and Federgruen and Zipkin, (1984 a, 1984 b) provide test heuristic procedures for ordering and allocating inventories within a distributor-retailer system. However, they restrict themselves to a system in which the warehouse holds no inventory. Jackson (1988) continues this work by including policies in which warehouse allocates only a portion of its given initial inventory to n identical retailers. The use of a central distribution center to hold stock and assign it to local distribution centers reduced backorders compared to a system with no central stock. Jonsson and Silver (1986) considered a two-echelon inventory system with one central warehouse and n identical regional warehouses. They found that holding a portion of inventory at a central warehouse and distributing it with the retailers reduces the total backorders. Rogers and Tsubakitani (1991) developed a single-period, single-component, multi-level inventory problem with one supplier of a common component part and n finished-goods items with backorder optimization. Their objective was to minimize the sum of penalties associated with expected backorders at the goods level by selecting the optimal inventory levels for the common component and finished goods subject to a budget constraint for total system holding costs. Graman and Magazine (2002) modeled analytically the relationship of inventory investment to demand variability and target service level. In their model inventory can be stored in an intermediate form. On realization of demand all the finished goods are used first, and then the semi-finished product is used to satisfy the demand. Through a numerical study they show that very little postponement capacity can actually provide all the benefits related to inventory reduction. Each of the multi-echelon models described are cost based models, whereas the approach used by Graman and Magazine (2002) focuses on the inventory service-level tradeoff.

Whang and Lee (1998) showed how the respective values of postponement from resolution of uncertainty of demands and forecast accuracy can be calculated in a simple build-to-stock model. They found that when the value of forecast improvement is large, the reduction in safety stock increases. During this time the resolution of uncertainty was also small. But as the resolution of uncertainty dominates the value of forecast improvements the reduction in safety stock decreases. They also found that due to postponement, there is a reduction in safety stock at a decreasing rate. Van Mieghem (2004) analyzed a model with two products where each product is assembled from two components. He assumed that both common and product specific components are stocked and drives conditions under which commonality should be adopted. He stated this condition in terms of a maximal commonality threshold cost that depends on the demand forecast only through its correlated demand and financial data. He found that for high commonality cost, neither commonality nor postponement is optimal. A pure commonality strategy where each product is assembled using a common component, however is never optimal unless complexity costs are introduced. Van Mieghem (2004) showed that while the value of the commonality strategy decreases in demand correlation between products, commonality is optimal even when the product demands are perfectly correlated. Su et al., (2005) concentrated on component commonality, postponement, and/or delayed differentiation. They studied the effectiveness of these strategies. First, they evaluated the inventory costs for various percentages of component commonality substitution. Second, they analyzed the performance of two postponement strategies and their relationship with product proliferation. They also calculated the cost and benefits of implementing delayed differentiation in a make-to-order environment and provide insights for choosing the point of differentiation.

3. MODELING

This section explains, in detail, the basic structure of the system under study. The system is modeled and then analyzed through simulation experiments. Two models are developed, one for the non-postponement scenario and one for the postponement scenario. The models are used to identify the advantages from postponement by comparing the two scenarios. The effect of the single-item, multiple–product situation on the inventory-service level tradeoff is examined. A manufacturing system is considered that produces a single item and then the item is packaged into multiple products. The following assumptions are made:

- Each product contains different discrete quantities of the common item
- Products differ from one another only in the quantity of the common item
- The demand for the item is independent of the variety of the product sizes available

A single period, uncapacitated inventory model operating under a periodic review, order-up-to-level (R, S) inventory policy is examined.

3.1. Service Measure

Service level is the typical measure used to quantify a company's market conformance. Definition of service level varies from company to company. It is usually related to the ability to satisfy a customer. There is a direct relationship between the ability to achieve a certain level, and cost and performance of a supply chain. For example, variability of demand and lead times determine the amount of inventory that needs to be held in the supply chain. Estimating the back order penalty (stockout cost) that results from a lost sale is often difficult, companies set safety stock levels for products by setting a service level. Stockout cost includes components such as loss of goodwill and delays to other parts of the supply chain. A common substitute for a stockout cost is a service level (Nahmias 2001). Although there are a number of different ways to measure service level, it generally refers to either the probability of not stocking out or the proportion of demand satisfied directly from shelf. The term ***Fill Rate*** is often used to describe the proportion of demand satisfied directly from shelf. The symbol P_2 is used to represent fill rate. To satisfy a service level objective of P_2, it is necessary to obtain an expression for the fraction of demand that stocks out during the period. This is discussed in more detail in the next section.

3.2. Assumptions and the Model Parameters

The assumptions of the model are as follows.

1. The demand is probabilistic and follows a normal distribution
2. There is a negligible chance of no demand between reviews; consequently, a replenishment order is placed at every review
3. The value of R (review period) is assumed to be predetermined.

A single period, uncapacitated inventory model operating under a periodic review, order-up-to-level (R, S) inventory policy is examined. In a (R, S) control system a replenishment order is placed every R units of time.

The parameters of the model are the following:
D = demand (random) during one year period
$E(D)$ = mean demand during one year period

$$G_u(k) = \int_k^{\infty} (u_0 - k) \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-u_0^{\,2}}{2}\right) du_0$$

is a special function of the unit normal (mean 0, std dev 1) variable. $G_u(k)$ is used in finding the expected shortages/stockouts per replenishment cycle (ESPRC).

k = safety factor
L = replenishment lead time, in years
H = inventory holding cost, in \$ / unit / year
K = ordering cost in \$
J = cost of reviewing inventory level
SS = safety stock, in units
R = review interval, in years
S = order-up-to-level / base-stock level, in units
$\bar{x}_{L+R}$ = expected demand over a review interval plus a replenishment lead time, in units
σ_{L+R} = standard deviation over a review interval plus a replenishment lead time, in units
Because of the assumption two, we have

$$\text{Number of replenishment orders placed per year} = \frac{1}{R} \tag{1}$$

The relevant equations for safety stock, ***Expected Shortage per Replenishment Cycle*** (ESPRC) and service level are presented.

A ***Safety Stock*** (SS) is held in case demand exceeds expectation; it is held to counter uncertainty. As the demand is uncertain and may exceed expectation, safety stock is needed to satisfy an unexpectedly high demand. Suppose that the demand (x) has a probability density function $f_x(x_0)$ such that

$f_x(x_0)dx_0$ = Prob {total demand lies between x_0 and $x_0 + dx_0$ }
then,

Safety Stock, *SS* = E (net stock just before replenishment arrives)

$$= \int_0^\infty (S - x_0) f_x(x_0) dx_0 \qquad (2)$$

that is,

$$SS = S - \bar{x}_{L+R} \qquad (3)$$

The equation 3 states that the average inventory level just before replenishment arrives is equal to the inventory level when the replenishment is placed reduced by the average demand during the lead time and review period.

The ***Expected Shortage per Replenishment Cycle*** (ESPRC) is defined as:

$$\text{ESPRC} = \int_S^\infty (x_0 - S) f_x(x_0) dx_0 \qquad (4)$$

When the demand is probabilistic the inventories can be categorized into different levels. In this article, Net stock is used as our stock level, which is defined as:

***Net Stock* (NS) =** On hand (OH) – Backorders (BO)
that is,

$$NS = OH - BO$$

Therefore,

$$E(NS) = E(OH) - E(BO) \qquad (5)$$

We assume that the average backorders are small relative to the average on-hand stock, we have

$$E(OH) \approx E(NS) \qquad (6)$$

Using equations 5 and 6,

E (OH just before a replenishment arrives) $\approx$ safety stock = $SS = S - \bar{x}_{L+R}$

E (OH just after a replenishment arrives) $\approx$ S - $\bar{x}_{L+R} + E(D)R$

The expected value of *E (OH)* over a cycle may be approximated by *0.5* (expected value of *OH* just before a replenishment arrives) + *0.5* (expected value of *OH* just after a replenishment arrives). Thus,

$$E(OH) \approx S - \bar{x}_{L+R} + \frac{E(D)R}{2} \qquad (7)$$

The safety stock can be expressed as,

$$SS = k\sigma_{R+L} \tag{8}$$

This is the amount of inventory required to protect against deviations from average demand during a period of *R+L* years. To this point the results hold for any probability distribution of *R+L* time demand. We assume a normal distribution and the safety stock is expressed as in Equation 8, then Equation 4 simplifies to

$$ESPRC = \sigma_{R+L} G_u(k) \tag{9}$$

The normal loss function, $G_u(k)$, is defined by the fact that $\sigma_{R+L} G_u(k)$ is the expected number of shortages that will occur during a replenishment cycle.

The ***Service Measure*** (P_2) is defined as the percentage of all the demand that is met on time and *E (D)* is the average annual demand.

$$\frac{Expected\ Shortages}{Cycle} = ESPRC \tag{10}$$

$$\frac{Expected\ Shortages}{Year} = ESPRC \frac{1}{R}$$

$\frac{1}{R}$ = number of replenishment orders placed each year, and

Fraction of demand satisfied directly from shelf = 1- Fraction backordered

Therefore,

$$1 - P_2 = \frac{Expected\ Shortages\ per\ year}{Expected\ demand\ per\ year}$$

$$= \frac{ESPRC}{R} * \frac{1}{E(D)} \tag{11}$$

Equation 11 can be used to determine the base stock that yields a desired service level. We assume the lead time demand to be normally distributed, with mean $\bar{x}_{R+L}$ and standard deviation σ_{L+R}. To use the Equation 11, we need to determine *ESPRC* and the determination of *ESPRC* requires knowledge of normal loss function $G_u(k)$. Where,

$$k = \frac{S - \bar{x}_{R+L}}{\sigma_{R+L}}$$

Therefore,

$$ESPRC = \sigma_{R+L} G_u (\frac{S - \bar{x}_{R+L}}{\sigma_{R+L}}) \tag{12}$$

Substituting Equation 11 into 12, we get

$$G_u (\frac{S - \bar{x}_{R+L}}{\sigma_{R+L}}) = \frac{E(D)R(1-P_2)}{\sigma_{R+L}} \tag{13}$$

Thus, S can be determined from Equation 13. More details about the inventory policy can be obtained from Silver et al. (1998). Models of similar inventory systems to the ones developed above are also discussed in Winston (2004).

3.3. Non-Postponement Scenario: Here we describe the non-postponement case (Figure 1). We make the following assumptions:

- There are multiple products and each product contains a common item in various quantities
- The multiple products are managed as separate finished goods inventories

The demand during the single period for product $y,\ y = 1,2,....,m,$ is a random variable, X_y, with a realization of demand denoted by x_y, having probability density function (p.d.f.) $f_y(x_y)$ and cumulative density function (c.d.f.) $F_y(x_y)$, with expectation

$$E(X_y) = \mu_y \quad \forall y \tag{14}$$

and variance

$$\mathrm{var}(X_y) = \sigma_y^2 \quad \forall y \tag{15}$$

Let,

S_y = non postponement inventory level for product y

To compare the non-postponed and postponement inventory levels, we need to express both inventories in terms of the common item. The inventory level for the non-postponed case is the sum of product inventory levels expressed in terms of the common item,

$$I_N = \sum_y n_y S_y \tag{16}$$

Where n_y is the quantity of the common item contained in product y.

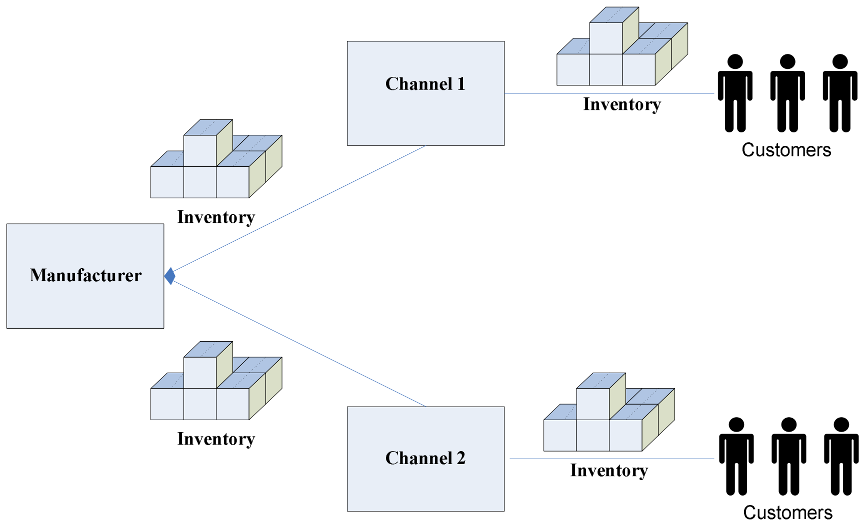

Figure 1. Traditional Supply Chain (Non-Postponement Case)

3.4. Postponement Scenario: In the postponement case (Figure 2), items are not packaged for shipment until a customer order for the product is received. Packaging postponement is used to improve the customer service levels. The model assumes that postponement causes no shortages due to increased delivery lead-time caused by postponement.

Let,

J = Demand in terms of items as a random variable

Demand J is a linear combination

$$J = n'X = n_1 X_1 + n_2 X_2 + ... + n_m X_m$$

of m-product having probability density function $f(j)$, with mean

$$\mu = E[n'X] = \sum_{y=1}^{m} n_y \mu_y \tag{17}$$

and variance

$$\sigma^2 = Var[n'X] = \sum_{y=1}^{m} n_y^2 \sigma_y^2 + 2\sum_{i=1}^{m-1} \sum_{y=i+1}^{m} n_i n_y \rho_{iy} \sigma_i \sigma_y \tag{18}$$

Where,

n = the column vector of quantities of item per product,
X = the product-demand random vector and
ρ_{iy} = the correlation of X_i with X_y.

Using the mean and variance, the postponement inventory I_P can be determined using equation 13. In postponement case the inventory is reduced because the standard deviation of demand in postponement is less than the sum of the standard deviations of demand for non-postponement. Due to the aggregation of demand across multiple products, one major benefit of postponement is the pooling of risk associated with the different customized end products. Risk pooling is an important concept in supply chain management. In risk pooling the demand variability is reduced by aggregating demands across different locations. This is due to the fact that as we aggregate demand across different locations, it becomes more likely that high demand from one customer will be offset by low demand from another. This reduction in variability allows a decrease in safety stock and therefore reduces average inventory. Risk pooling reduces the amount of inventory required to support the same level of service, the degree of benefit depends on the unpredictability (variance) and dependence (correlation) of the demand of the end products.

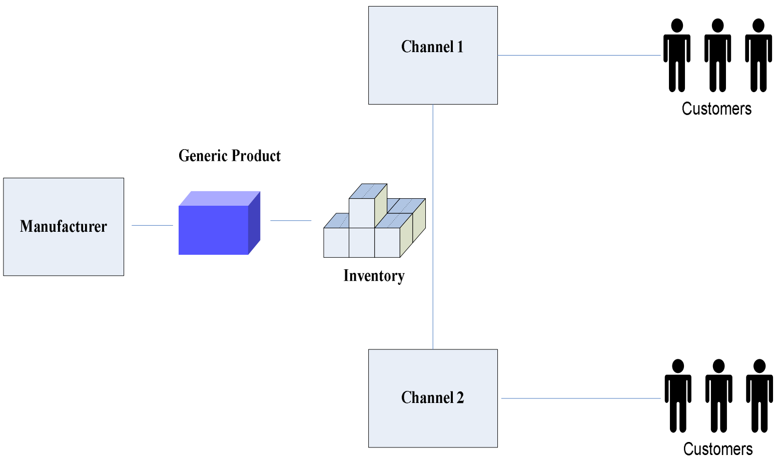

Figure 2. Supply Chain with a Generic Product (Postponement Case)

3.5. The Simulation Model

Both postponement and non-postponement scenarios are coded as discrete event simulation models using Arena – Version 7.01. The inputs to the model are the inventory policy information and the demand information. We require the following information about the inventory policy:

- Safety stock level / base stock level
- Reorder point
- Review period
- Lead time

The time between demands are *independent and identically distributed* random variables having normal distribution. The company reviews the inventory level after every 12 days and the order arrives after the specified lead time. When a demand occurs, it is satisfied immediately if the inventory level is at least as large as the demand. If the demand exceeds the inventory level, the excess of demand over supply is backlogged and satisfied by future deliveries. When an order arrives, it is first used to satisfy the backlog and the remainder is added to the inventory. The model uses the following types of events;

- Arrival of an order
- Demand for the product
- Inventory evaluation at the review period
- End of simulation after n months

We watched the behavior of the inventory level in the system. In case of lead time of one week, review period of twelve days, monthly demand of 1000 units and coefficient of variation of 0.4, the system stabilized after 19 days. The simulation was run for 336 days. The stabilization period is quite small as compared to the run-length of 336 days. With this into consideration we go for the replication/deletion approach to estimate the means. We have used Arena's output analyzer to determine the warm-up period. Confidence Intervals at 95% confidence level were set in estimating the means. Two-level Fractional Factorial Experimental designs are used to study and analyze the output from simulations. Design of Experiments (DOE) is used to analyze the performance of service level, inventory levels and to determine which variables are most influential. Additionally we determine how the variables interact among themselves in the supply chain environment with and without postponement strategies.

4. ANALYSIS OF POSTPONEMENT STRATEGIES

This section presents a numerical analysis of the impact of postponement on the performance of supply chains. The model developed has been tested for various instances of the problem. Postponement is considered to be advantageous if the amount of item inventory required for postponement is less than the item inventory required for non-postponement given same service levels. The item inventory is considered equal to the base stock level, which is defined in section 3. The greater the difference in the two inventories, the greater the benefit of postponement. Also postponement enables companies to dramatically reduce inventory while improving customer service. The objective of this section is to get insight into the response of item inventory levels of the system in both non-postponement and postponement scenarios for different levels of the model parameters. Demand variability, correlation of demands, number of products being postponed, inventory levels and fill rate are explored. Design of Experiment (DOE) is used to conduct and analyze controlled tests to evaluate the factors that control the value of the inventory level. Two-level Fractional Factorial Experimental designs are used to study and analyze the performance of inventory levels and to determine which system variables are the most influential on the inventory levels. Additionally we determine how the variables interact among themselves in the supply chain environment with and without postponement strategy.

In this analysis a 7-factor, 1/8 fraction, resolution IV design is used. The statistical software Minitab – Release 14 is used to conduct the experimental design. Whereas the system response is **WI**- Weeks of Inventory, the factors considered are the following:

- **Post -** Postponement
- **DVar1**– Demand Variability1 (due to change in the coefficient of variation)
- **DVar2**– Demand Variability2 (due to change in the mean)
- **DCorr**– Demand Correlation
- **LT**- Lead Time
- **FR**- Fill Rate
- **NP**- Number of Products

The levels of the factors used are presented in Table 1 and the design matrix is given in Table 2. As seen in Table 1, the sequence of the experiments is randomized. The randomization of run order ensures that replicate runs are at the same experimental conditions and that variation between runs and biases are eliminated or considered at all conditions. The confounding pattern for the fractional design is shown in Table 3. Table 4 contains the estimated effects and coefficients from the experiment. Figure 3 presents a normal probability plot of the effect estimates from this experiment. The main effects of A, C, and F and the interaction AC are significant at 95% confidence interval. Figure 4 is a normal probability plot of the residuals and the plot is satisfactory. An approximate 95% confidence intervals (curved lines) for the fitted distribution are displayed in Figure 4. These confidence intervals are point-wise and they are calculated separately for each point on the fitted distribution. As the diagnostic check, the residual plot confirms that the model developed is adequate.

Table1. The Levels of the Factors

Notation		Post	DVar1	DVar2	DCorr	LT	FR	NP
Upper Level	High	Using postponement	0.4	1100	0.8	8	95	9
Lower Level	Low	Not using postponement	0.2	700	-0.8	4	80	3

Table2. The Experimental Design Matrix

Std Order	Run Order	Post	D Var1	D Var2	DCorr	LT	FR	NP	WI
1	10	Low	Low	Low	Low	Low	Low	Low	**0.93**
2	6	High	Low	Low	Low	Low	Low	High	**0.75**
3	2	Low	High	Low	Low	High	High	Low	**2.67**
4	11	High	High	Low	Low	High	High	High	**2.10**
5	9	Low	Low	High	Low	High	High	High	**3.56**
6	12	High	Low	High	Low	High	High	Low	**2.89**
7	13	Low	High	High	Low	Low	Low	High	**2.13**
8	5	High	High	High	Low	Low	Low	Low	**1.58**
9	8	Low	Low	Low	High	High	High	High	**2.48**
10	7	High	Low	Low	High	High	High	Low	**2.02**
11	16	Low	High	Low	High	Low	Low	High	**1.29**
12	14	High	High	Low	High	Low	Low	Low	**0.79**
13	3	Low	Low	High	High	Low	Low	Low	**2.45**
14	15	High	Low	High	High	Low	Low	High	**1.47**
15	4	Low	High	High	High	High	High	Low	**3.92**
16	1	High	High	High	High	High	High	High	**2.64**

Table 3. Confounding Pattern of the Factors

Alias Structure of the Factors
Postponement
DVar1
DVar2
DCorr
LT
FR
NP
Postponement*DVar1 + DVar2*LT + FR*NP
Postponement*DVar2 + DVar1*LT + DCorr*NP
Postponement*DCorr + DVar2*NP + LT*FR
Postponement*LT + DVar1*DVar2 + DCorr*FR
Postponement*FR + DVar1*NP + DCorr*LT
Postponement*NP + DVar1*FR + DVar2*DCorr
DVar1*DCorr + DVar2*FR + LT*NP

Table 4. Estimated Effects and Coefficients for FR (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		2.1044	0.00438	481	0.001
Postponement	-0.649	-0.324	0.00438	-74.14	0.009
DVar1	0.0712	0.0356	0.00438	8.14	0.078
DVar2	0.9513	0.4756	0.00438	108.71	0.006
DCorr	0.0562	0.0281	0.00438	6.43	0.098
LT	0.0312	0.0156	0.00438	3.57	0.174
FR	1.3612	0.6806	0.00438	155.57	0.004
NP	-0.104	-0.052	0.00438	-11.86	0.054
Postponement*DVar1	-0.076	-0.038	0.00438	-8.71	0.073
Postponement*DVar2	-0.221	-0.111	0.00438	-25.29	0.025
Postponement*DCorr	-0.156	-0.078	0.00438	-17.86	0.054
Postponement*LT	-0.096	-0.048	0.00438	-11	0.058
Postponement*FR	-0.096	-0.048	0.00438	-11	0.058
Postponement*NP	0.0237	0.0119	0.00438	2.71	0.225
DVar1*DCorr	-0.016	-0.008	0.00438	-1.86	0.314

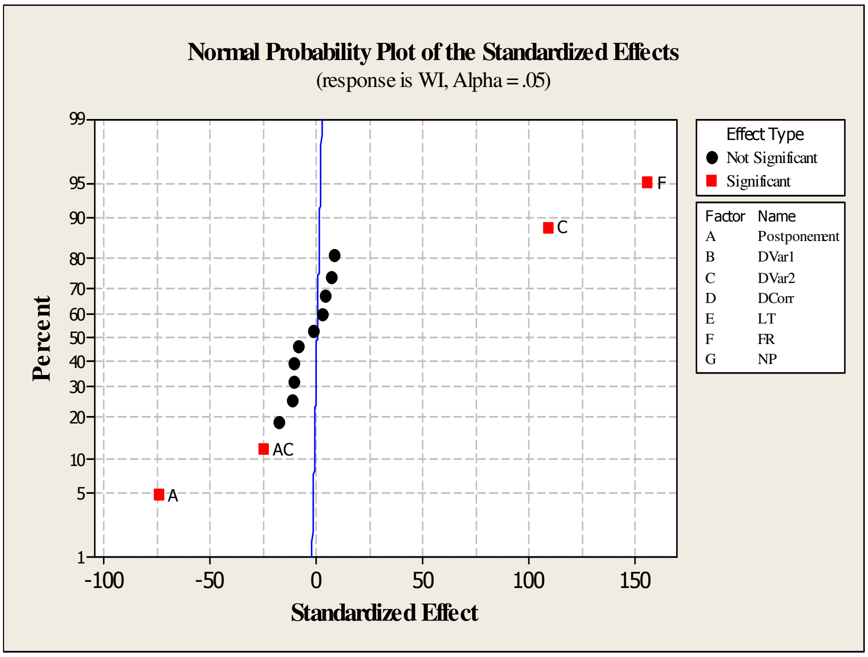

Figure 3. Normal Probability Plot of Effects

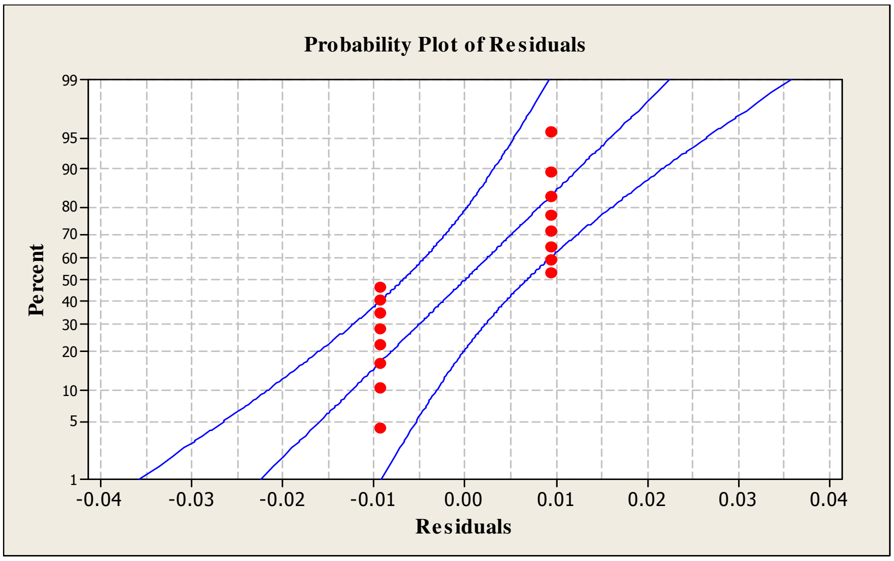

Figure 4. Normal Probability Plot of the Residuals

Equation 19 gives the regression model for predicting the weeks of inventory.

$$\hat{WI} = 2.10 - (\frac{0.65}{2}) * Postponement + (\frac{0.95}{2}) * DVar2 + (\frac{1.36}{2}) * FR - (\frac{0.22}{2}) * Postponement * DVar2 \quad (19)$$

If we shift from non-postponement to postponement, its main effect will be to decrease inventory level by an amount of 0.32. Postponement will have a negative effect on inventory level. Postponement helps to reduce the inventory required. The main effect of demand variability, DVar2 causes an increase in inventory level when DVar2 increases. As the demand variability increases the inventory level increases by an amount of 0.48. More the demand variability more inventory will be required to satisfy the demand. The main effect of fill rate, FR causes an increase in inventory level when FR increases. To satisfy more demand or to increase the fill rate more inventory is required. The main effect of this factor is 0.68. A simultaneous increase in postponement and demand variability decreases the inventory level. This interaction effect is 0.11. We believe postponement being a dominating factor, the interaction effect of increasing both the values decreases the inventory level.

Figure 5 shows the main effect plot for inventory level. Postponement has a negative effect and factors such as fill rate and demand variability have a positive effect on the inventory level. If one shifts from non-postponement to postponement the inventory level decreases. If one desire to have a better fill rate the weeks of inventory increases. Demand variability has a positive effect on inventory level. If the demand variability is less, fewer inventories are required and if the demand variability is more, more inventories are required.

Figure 6 represents the interaction plots for inventory level. According to the figure if the demand variability is more, overall inventory levels are lower in postponement. As the demand variability increases the uncertainty increases and postponement performs better in this situation.

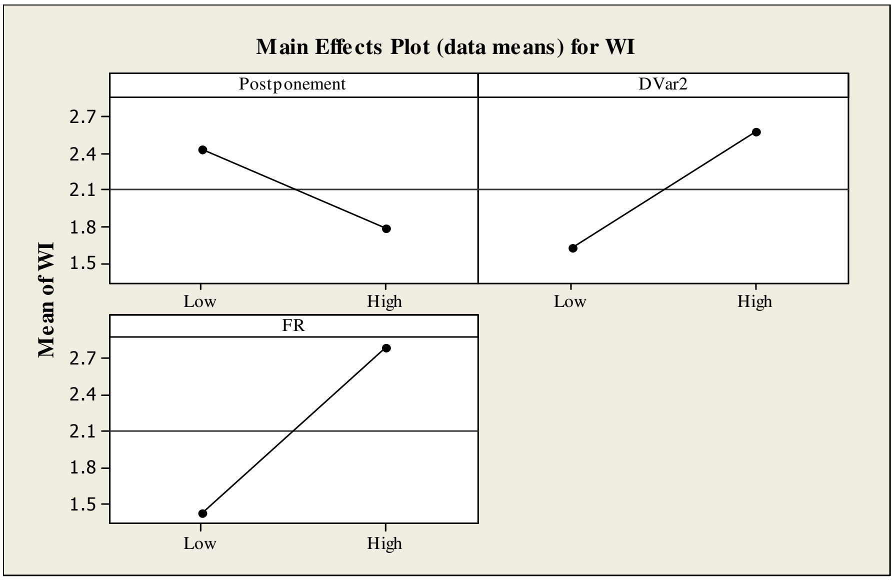

Figure 5. Main Effect Plot for WI

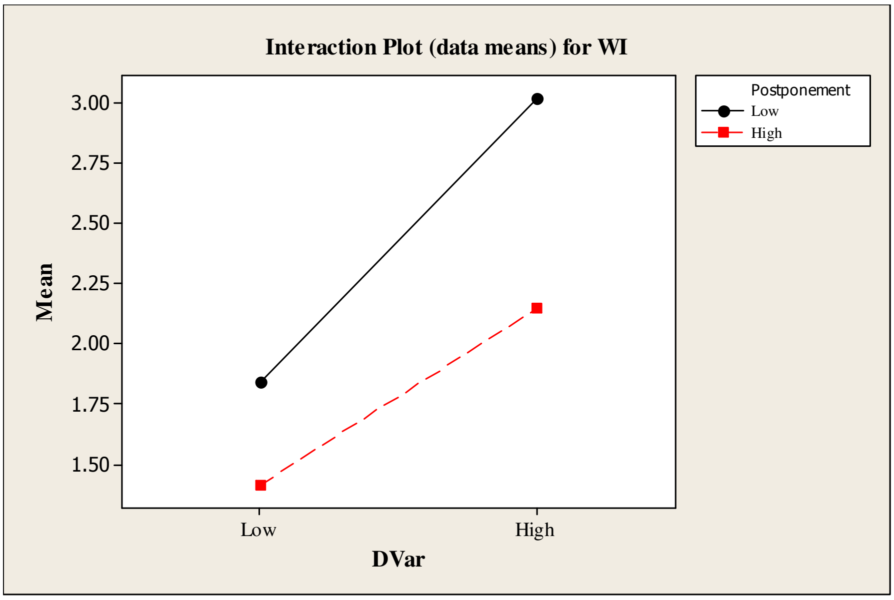

Figure 6. Interaction Plot of Postponement and Demand Variability

5. CONCLUSIONS AND FUTURE RESEARCH

In this article we studied the effectiveness of strategies like component commonality and delayed product differentiation. We also study how customer service level as well as inventory levels is affected by various parameters. Simulation modeling is used to capture the uncertainty and stochastic nature of the model. Example problems are solved to identify the parameters which significantly influence the inventory level and the results from the non-postponement and postponement scenarios are compared. We found that the main effects of A (postponement), C (demand variability), and F (fill rate) and the interaction AC are significant. If one shifts from non-postponement to postponement the inventory level decreases. If one desire to have a better fill rate the inventory level increases. Demand variability has a positive effect on inventory level. If the demand variability is less, fewer inventories are required and if the demand variability is more, more inventories are required. If the demand variability is more, overall inventory levels are lower in postponement. As the demand variability increases the uncertainty increases and postponement performs better in this situation.

Additional future research issues include the integration of other parameters such as product life cycle, delivery frequency, economies of scale and product/process design to construct a more sophisticated model.

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