African Journal of Business Management Vol. 6(14), pp. 4752-4760, 11 April, 2012
Available online at http://www.academicjournals.org/AJBM
DOI: 10.5897/AJBM11.1576
ISSN 1993-8233 ©2012 Academic Journals

Review

Establish a collaborative production-procurement system with contract portfolio approach

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Accepted 19 December, 2011

This paper focused on the treatment of supply disruptions in the production and procurement systems. By treating inventory as real options, a contract portfolio can be generated to hedge the supply disruptions with minimal costs. This paper proposed a collaborative production-procurement system with contract portfolio approach to smooth supply disruptions incurred from supply chain. The collaborative production-procurement system provided a strategic flexibility and adopted for a real-life production-procurement problem which was faced by a food processing industry in Asia and turns out to be very efficient. The proposed contract portfolio approach has provided evidence of better results than the traditional operational techniques in this paper.

Key words: Supply disruption, contract portfolio approach, real option.

INTRODUCTION

According to Lee (2002), before choosing a supply chain strategy, it is necessary to understand the sources of the uncertainties and explore ways to reduce these uncertainties. There are two types of uncertainty reduction strategies: demand uncertainty reduction strategies and the supply uncertainty reduction strategies. The first aims at reducing the demand uncertainties, such as avoiding the bullwhip effect, by using information sharing and collaborative replenishments. Supply uncertainty reduction strategies aim at reducing or even avoiding uncertainties concerning supply.

Due to the differences in the goals and strategies of supply chains, different measures for different types of supply chains are necessary to determine the value and competitiveness of a supply chain.

Lee (2002) also presents ‘the uncertainty framework’, which considers dimensions of demand and supply uncertainties. This framework can be a simple but powerful way to characterize a product; which can be useful in devising an appropriate supply chain strategy for that product. Uncertainties in demand and supply can result in excessive inventories and deteriorated customer service, indicating out of control supply chain. In the presence of uncertainties, it is difficult to foresee the final effects of the actions taken and hence to manage the inventories efficiently. In general, it is observed that stochastic lead times and demand have their greatest impact in combination (Williams and Tokar, 2008). In this era of outsourcing, procurement and/or off-shoring longer lead times are common, especially because the transportation time might be considerable. Usually, long lead times and uncertain demand hamper the performance of inventory control systems. These issues have even more pronounced effects in the presence of stochastic lead times.

In supply chain management, contracts have special parameters that focus especially on funds, material and information (that coordinate the supply chain), while disregarding clauses that are important in other areas. Chopra and Meindl (2001) give a good definition of contracts for supply chain management: “A contract specifies the parameters within which a buyer places orders and a supplier fulfills them. A contract may contain specifications regarding quantity, price, time and quality”. It is widely believed in industry that long-term relationships

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between firms in form of long-term contracts are superior to short-term relationships due to cost savings. Long-term contracts are advantageous, if they lead to reduction in purchase prices and improvement in delivery lead time performance. Short-term contracts are advantageous due to the speculative advantage as well as the flexibility to switch to other suppliers and near-zero fixed investments (Hirschhausen and Neumann, 2008). More research regarding to the comparison of advantages and disadvantages between long-term contracts and short-term contracts can be found in (Lian and Deshmukh, 2009; Peleg et al., 2002; Tomlin, 2006; Murray, 2009).

The supply and demand characteristics are a way to look at uncertainties of a supply chain. Yet, there may be supply chains where the explicit distinction of a third type of uncertainty mentioned in Lee (2002), namely the process uncertainty, may be important. This third type of uncertainty relates to the production of the product itself, that is, the supply chain of production and procurement within a firm, which relates to the supply side and the demand side. Yet, it is intrinsic to the production process itself. If the process uncertainty plays an important role in the supply chain, explicit distinction may be advantageous.

Therefore, by using inventory as real options, a risk-hedging supply chain from the food processing industry is modeled based on contract portfolio approach to smooth supply disruptions in a collaborative production-procurement system and proposed in this paper.

CONTRACT PORTFOLIO APPROACH WITH REAL OPTIONS

The integration of uncertainty and management of risk has become central to research in the global operations arena and supply chain management. Research on this front addresses two fundamental questions, albeit in different contexts. First, how do operating and/or financial uncertainty and its consequent risks affect operating policies? Secondly, what are the ensuring economic ramifications and insights when uncertainty is explicitly accounted for and related risks are truncated?

In the early 1990s, researchers began to embed supply disruptions into classical inventory models, assuming that a firm's supplier might experience a disruption when the firm wished to place an order (Nahmias, 2005; Williams and Tokar, 2008). Examples include models based on the economic order quantity (EOQ) model (Chung, 2008; Schmitt et al., 2010), *(R, Q)* model (Handfield et al., 2009; Mohebbi and Hao, 2008), and the *(s, S)* model (Lian and Deshmukh, 2009). Firms have a range of strategies for managing disruptions. Our focus in this paper is on the use of inventory to mitigate the impact of disruptions. Inventory managers who ignore the risk of supply disruptions will encounter excess costs when disruptions occur, in the form of stockout costs, expediting costs and loss of goodwill. On the other hand, disruptions at a given location are typically relatively infrequent, so holding too much extra inventory is costly, as well. An effective inventory policy should strike a balance between protecting against stockouts during disruptions and maintaining low inventory levels, related research also can be found in (Akella et al., 2002; Li and Kouvelis, 1999; Lin and Chen, 2009; Peleg et al., 2002; Seifert et al., 2004).

Cohen and Agrawal (Hirschhausen and Neumann, 2008) solve a stochastic dynamic programming formulation using simulation to analyze the trade-off between long-term and short-term contracts. The elements that dominate are the uncertain prices of the spot market versus fixed investment costs and learning cost reductions by the long-term supplier, along with the usual inventory and backlog costs. As mentioned above, their model considers a planning horizon of several years, which are divided into tactical review periods of the length of one week. Once a long-term contract is selected, it lasts for the remainder of the horizon (exclusivity of the different contract types). The short-term contract lasts for the duration of a tactical review period.

Peleg et al. (2002) analyze three different scenarios analytically: A short-term e-procurement strategy, a long-term contract and a combined strategy for a fixed number of suppliers for these two periods. The same scenarios are simulated again for two periods taking the optimal number of suppliers in account for short-term procurement. Peleg at al. (2002) showed that one of the scenarios is optimal. The selection of the contract type depends on the distribution of the lowest market price and contract terms, such as the cost improvements in period 2 (in case of the long-term contract) and the minimum quantity to purchase from the long-term seller in period 2 (in case of the combined strategy).

Seifert et al. (2004) advocates a portfolio procurement approach by analyzing two supply options, namely, spot markets and contract procurements, separately. Under supply option 1, a buyer uses a forward contract with known lead time and fixed unit price. Under option 2, a buyer uses a spot market with essentially negligible lead time but stochastic spot price. The model assumes stochastic demand and units purchased via both options can be used to fill this demand. Given some key parameters, such as demand and spot price volatilities, correlation between demand and spot price, and risk aversion, Seifert et al.'s approach can be used by decision makers to identify commodities for which the use of spot markets is attractive and for determining optimal procurement strategies for those commodities. The model allows to explicitly quantify the potential performance gains by procuring via spot markets. Significant profit improvements can be achieved if a moderate fraction of the demand is procured via spot markets.

Akella et al. (2002) present a model for standardized services whose objective is the determination of the optimal strategy a risk-neutral buyer should adopt when two main modes of supply are available: A long-term procurement channel defined by a reservation capacity level and procurement through a spot market. The buyer must satisfy his aggregated demand via the two procurement channels. In order to achieve his serviceability obligations and hedge against the variability of demand and supply, the buyer offers his seller a long-term contract, where in period 1, the buyer determines a capacity reservation level, based on a pricing scheme that is dependent on the demand. In period 2, the buyer has to satisfy a random demand.

Li and Kouvelis (1999) present a study of the performance of different contracts in an environment of uncertain prices due to exchange rate movements but with deterministic demand. They study different contracts with features, such as flexibility concerning delivery time, flexibility concerning quantity, and risk-sharing for purchase prices. Similar to real options, time-flexible and quantity-flexible contracts provide a buyer with a certain amount of freedom when to buy and how much to buy. As a consequence, these types of contracts can be interpreted similar to real options. They find that time-flexibility provides substantial benefits in environments with low holding costs and highly dynamic environments.

Furthermore, Lin and Chen (2010) repose the research theme of simultaneously making inventory hedging and optimal routing assignment decisions that coordinate replenishment and shipment policies. Firstly, a generalized autoregressive conditional heteroskedasticity (GARCH) (Park and Ber, 2009; Bentarzi and Hamdi, 2008) model is proposed to effectively deal with demand heteroskedasticity and provide a set of demand forecasting data, including the means and standard deviations, in a given planning horizon. Secondly, from the hedge point of view, the inventory portfolio policy, based on the demand forecasting through GARCH model, can be generated through hedging with forward option pricing model (FOP model) to maximize the total net present value (NPV). Finally, through optimizing the delivery schedule based on the optimal common review period determined through the inventory portfolio policy, the distribution policy can be generated.

MODEL GENERATION

A collaborative production-procurement system with contract portfolio approach model is proposed as follows: First, a hedge based *(R, s, S)* inventory policy has been used in this paper to generate demand orders from retailers. Then, an aggregative demand of inventory through GARCH model can be generated to obtain an optimal aggregative *(R, s, S)* replenishment policy for production. Secondly, based on the production conditions, an optimal production cycle in a given planning time horizon can be obtained to minimize the total production costs and maximize the replenishment service level. Finally, based on the optimal aggregative *(R, s, S)* replenishment policy, the long-term procurement contract can be generated. Meantime, based on the production cycle and transportation lead time incurred in long-term procurement contract, a short-term procurement can also be generated to hedge the risks of supply disruptions incurred in production and procurement processes. The flowchart of this collaborative production-procurement model is depicted in Figure 1.

As the model shown in Figure 1, the model is developed as follows:

Step I: A hedge based *(R, s, S)* replenishment policy with maximal net present value is developed with the following definitions:

i) Through fitting historical data D_t into Equations 1 and 2 to obtain the optimal forecasting model *GARCH(p, q)*, to provide a set of forecasting data $\{\overline{Q}_t, \tilde{\sigma}_t\}$ in a given planning horizon *H*:

$$Q_t = \beta_0 + \sum_{j=1}^{N_{y_t}} \varphi_j Q_{t-j} + \sum_{k=1}^{K} \sum_{i=1}^{N_{X_{k_t}}} \alpha_{k_i} X_{k_t - i} + \varepsilon_t \qquad (1)$$

$$\sigma_t^2 = \theta_0 + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \tau_j \sigma_{t-j}^2 \qquad (2)$$

where Q_t is the demand at instant *t* and X_{k_i} is the explanatory variable X_k (e.g. price etc.) at instant *i* that is used to explain variations in the dependent variable y_t. $N_{X_{k_t}}$ represents the period up to which the lagged values of X_{k_i} that will be used in the equation. α, β, θ and τ are coefficients to be estimated based on *X*, *Y*, ε and σ^2.

ii) Based on the FOP Model, Equations 3 to 9) with maximal net present value, to determine the optimal hedge period *t* to generate an optimal *(R, s, S)* replenishment policy:

$$V(t,Q) = e^{-r(t_\propto - t)}(SN(d_1) - S^* N(d_2)) \qquad (3)$$

with

$$S = P \min (D, \tilde{Q}) - ce^{h(t^* - t)}\tilde{Q} - B \max(D - \tilde{Q}, 0) \qquad (4)$$

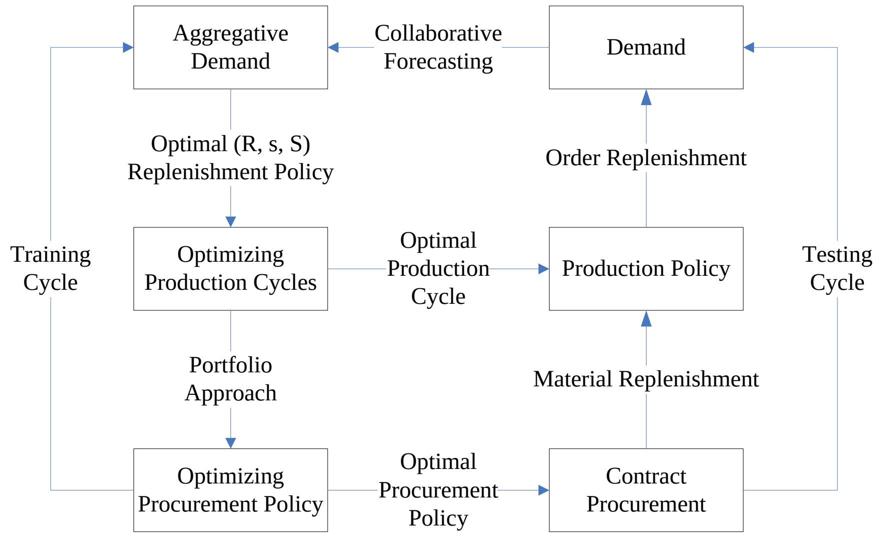

Figure 1. The flow chart of collaborative production-procurement system with portfolio approach.

$$S^* = (P-c)\tilde{Q} \tag{5}$$

$$\tilde{Q} = \bar{Q}[1+\sigma(t,Q)\sqrt{t_{ex}-t}\xi] \tag{6}$$

$$d_1 = \frac{\log(S/S^*) + (r+\sigma(t,Q)^2/2)(t_{ex}-t)}{\sigma(t,Q)\sqrt{t_{ex}-t}} \tag{7}$$

and

$$d_2 = d_1 - \sigma(t,Q)\sqrt{t_{ex}-t} \tag{8}$$

where ξ is Gaussian with mean 0 and variance 1, and *c*, *r* and *h* are the unit inventory purchasing cost, free interest rate and the unit inventory holding cost, respectively. The *N(.)* represents the standard normal distribution. Moreover, the optimal safety stock for this contract investment can be determined by:

$$s = V(t,Q)/c \tag{9}$$

with the hedge $\delta \equiv N(d_1) \geq 0.5$.

Step II: Optimizing production policy with dynamic demand in equal production cycle with following definitions and assumptions:

i) A uniformly distributed production rate *p* with a constant deficit rate *r* in production period T .

ii) Over time production and backlog are not allowed

iii) $(R^p(k), s^p(k), S^p(k))$ is used as a smoothing production policy in production period *k*.

iv) A unit penalty cost B^p is charged while shortages occurred in replenished period.

v) The objective function (Equation 10) is used to find the optimal production cycles in production period T to minimize the total production costs:

$$\text{Min} \quad TC^p(N^p) = \frac{T}{N^p}K^p + \int_{t=1}^{T} H^p I^p(t)dt + \sum_{n=1}^{T/N^p}\sum_{i=1}^{N^r} B^p QS^p(n) \tag{10}$$

vi) $d^p(t)$: the demand for replenishment at time *t*, where

$$d^p(t) = \sum_{i=1}^{N} O_i^r(t)$$

vii) $I^p(t)$: the inventory level of production center at time *t*, where:

$$I^p(t) = I^p(t-1) + QP^n(t) - d^p(t) \tag{11}$$

viii) $QS^p(n)$: the shortage occurred in production period n, where:

$$QS^p(n) = \begin{cases} 0 & if \quad I^p(t) \geq \sum_{i=1}^{N} O_i^r(t) \\ \sum_{i=1}^{N} O_i^r(t) - I^p(t) & otherwise \end{cases}$$

, where

$$1 \leq n \leq T/N^p \tag{12}$$

ix) $O^p(t)$: the ordering requirement of raw material in production period n.

Step III: An optimal collaborative contract portfolio procurement policy is developed based on the following definitions and assumptions:

i) Consider a portfolio procurement policy with long-term contracted procurement policies and a combination of option based short-term procurement policies (local procurements or purchasing from spot market) to maximize the total revenue of supply chain.
ii) The amounts of material requirements of long-term contracted policies are set to protect the minimal requirements of production.
iii) The unsatisfied amounts of material through long-term contracted policies are hedged through short-term option contracts with local suppliers or/and spot market.
iv. The objectives of portfolio procurement policy are:

- To decide the optimal procurement amount from each supplier in contract portfolio procurement policy to maximize the total revenue of whole supply chain under the sub-objectives of minimization of total procurement and production costs and maximization of total revenue of retailer sales.
- To optimize the call option for each supplier in portfolio procurement policy to minimize the risks of shortages incurred from procurement lead time and production volatilities.
- The requirement amount of long-term contract is calculated based on regular production requirement.
- Call options on short-term contracts provided by local suppliers or spot market are executed, when necessarily, to hedge the lead time volatilities incurred in long-term contract delivery.
- The objective to minimize the total procurement costs is as follows:

a) Based on the supplier base, the requirements of long-term contracts are determined based on the aggregative *(R, s, S)* replenishment policy in planning horizon *T*; then, a long-term contract (Q_j^c, R_j^c) procurement policy on supplier *j* is determined based on production requirement and delivery conditions.
b) Considering the safety stock requirement held in both production and retailers, the safety stocks, SS^c, for raw material are hedged through option contracts with short-term suppliers, where $SS^c = \sum_{j=1}^{N^s} QC_j^c$, N^s means a set of short-term contract suppliers.
c) $I^s(t)$: The inventory level of raw material on hand at time t

$$I^s(t) = I^s(t-1) + \sum_{j=1}^{N^l} Q_j^c + \sum_{j=1}^{N^s} QC_j^c - O^p(t) \geq 0$$

d) Based on the procurement strategy and supplier base, the optimal procurement problem is to decide how many raw material, $\sum_{j=1}^{N^l} Q_j^c$, should be purchased from long-term contractors and how many safety stocks of raw material, $SS^c = \sum_{j=1}^{N^s} QC_j^c$, should be hedged through short-term contractors.
e) Based on the demand forecasting model, a set of demand forecasting $\tilde{d}_i^r(t) = (\bar{d}_i^r(t), \sigma_i^r(t))$ in planning horizon T can be determined. Then, the requirement for long-term contracts can be calculated as:

$$\sum_{t=1}^{T}\sum_{j=1}^{N^l} Q_j^c(t) = \sum_{t=1}^{T}\sum_{i=1}^{N^r} \bar{d}_i^r(t)/(1-r) \tag{13}$$

and the requirement for short-term contracts is:

$$\sum_{t=1}^{T} SS^c(t) = \sum_{t=1}^{T}\sum_{j=1}^{N^s} QC_j^c(t) = \sum_{t=1}^{T}\sum_{i=1}^{N^r} \sigma_i^r(t)/(1-r) \tag{14}$$

- The objective function is defined as follows:

$$\textbf{Min} \quad TC^s(T) = \sum_{t=1}^{T}\sum_{j=1}^{N^l} C_j^c Q_j^c(t) + \sum_{t=1}^{T}\sum_{j=1}^{N^s} K_j^c QK_j^c(t) + \sum_{t=1}^{T}\sum_{j=1}^{N^s} CO_j^c QC_j^c(t) \tag{15}$$

where C_j^c is the contracted price of long-term contract *j* and K_j^C is the strike price of short-term contract *j* at the option executive date and $0 \leq QK_j^c(t) \leq QC_j^c(t)$ is the actual purchasing amount executed in short-term contract *j* at the option executive date; CO_j^c is the call option price of short-term contract *j*.

NUMERICAL EXPERIMENT AND ANALYSIS

Being a meat processing company in Asia, ABC Company mainly serves meat products, including beef, pork, lamb and chicken, to restaurants and super markets in Taiwan. The sales of ABC occupy more than 30% market shares in Taiwan's meat markets. Most of these materials can be obtained both from overseas (like America, New Zealand and Australia) and local spot market in Taiwan. By now, excerpts of chicken and parts

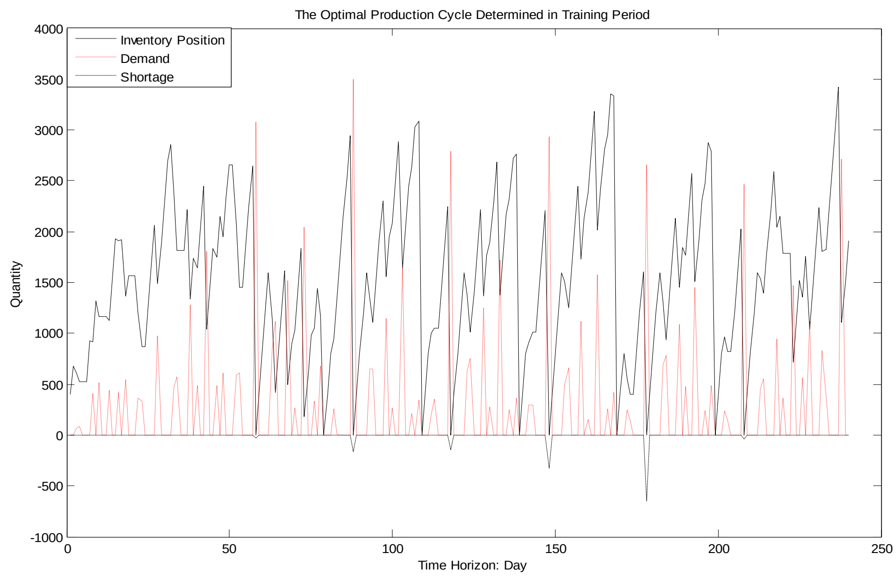

Figure 2. The optimal production cycle determined in training period.

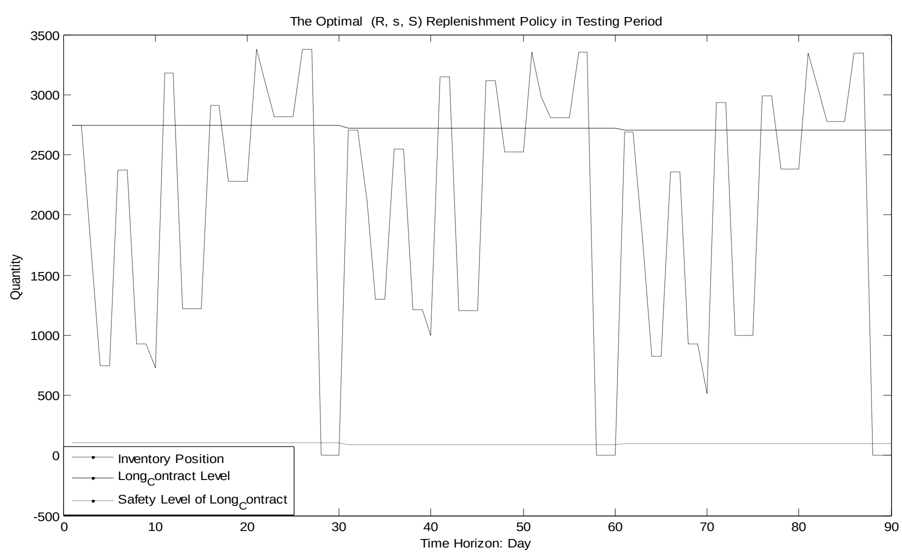

Figure 3. The optimal *(R, s, S)* replenishment policy in testing period.

of pork are purchased from local suppliers, the other materials are mostly purchased from key suppliers in overseas, for example, the key supplier of beef in USA is IBP. In this paper, we use the beef as our testing product, and also as material in our collaborative production-procurement system. In this case, for simple demonstration purpose, the long-term contract of beef is only considered to obtain from America and the short-term contract of beef is obtained from local spot market. Totally, 360 days trading data of a chain restaurant with 5 franchises in Taiwan, named customer X, in 2008 has been collected as experiment samples. The first 240 data has been used as training data and the other 90 data has been used as testing data based on the time series.

In training period, an aggregative *(R, s, S)* replenishment policy from customer X is used to train the production model (as the Step II mentioned earlier) to determine the optimal production cycle, that is, the number of productions in a planning horizon. After training, the optimal production cycle is 5 with an optimal shortage rate of 1.64%. The training result is as depicted in Figure 2.

Also based on the Step I, an aggregative *(R, s, S)* replenishment policy for beef in testing periods is generated and depicted in Figure 3.

Meanwhile, the optimal *(R, s, S)* replenishment policy

Table 1. The Optimal (R, s, S) replenishment policy in testing period.

Period	Optimal period	Up-to-Level	Safety Stock	Shortage	Production requirement
1	5	2,748	101	0	2,748
2	5	2,719	91	0	2,719
3	5	2,708	96	0	2,708

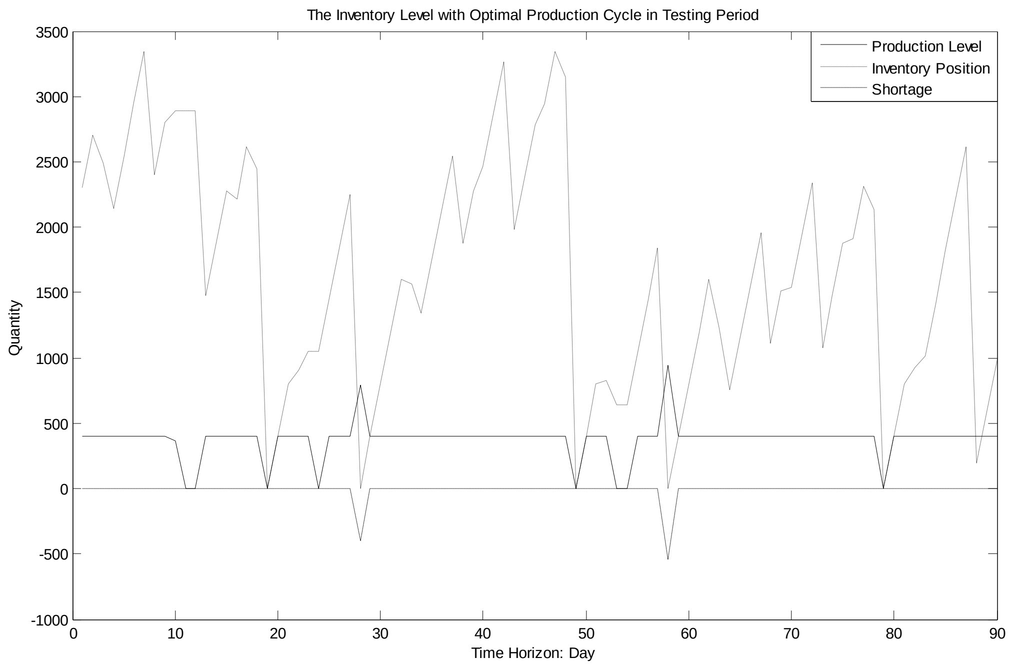

Figure 4. The inventory level with optimal production cycle in testing periods.

for ABC Company to serve their customer X in a 30-day planning horizon in testing period is obtained (through Equations 1 to 9) and presented in Table 1.

Based on Table 1, the production amount in each planning horizon can be calculated as up-to-level stock. Meanwhile, based on the optimal production cycle obtained from training period, the optimal production policy resulted in an optimal shortage rate of 2.79%, as depicted in Figure 4. For order-to-up-level policy, if a retailer periodically updates the mean and the variance of demand based on observed customer demand data, then the variance of the orders placed by the retailer will be greater than the variance of demand. That is why the shortage occurred in this experiment.

According to the optimal *(R, s, S)* replenishment policy and optimal *(Q, R)* production policy obtained from training period through Step I and II, an optimal contract portfolio can be determined through Step III. From a risk-averse point of view, a long-term contract is generated based on the optimal *(R, s, S)* replenishment policy obtained from testing period by setting the contract amount equal to up-to-level stock in each period in a planning horizon. Meanwhile, the short-term contracts executing in local spot market is determined based on the possibility of shortages might be incurred in lead time incurred in contract fulfillment and in production in each period in a planning horizon.

By treating inventory as real options, an optimal contract portfolio procurement policy can be generated, as depicted in Figure 5 and compared with traditional procurement policy, as depicted in Figure 6, generated from traditional operation approach, a safety stock setting based on the variances in demand and lead time in production under a given confidence service level (in this case we use 95% service level). Comparing Figure 5 with 6, the material levels in contract portfolio procurement policy are much less than they are in traditional operation procurement policy.

Moreover, from Table 2, with treating safety stocks as real options executed in spot market, even though a maximal short-term contract level has been determined, but, in this case, the average executed amount of short-term contracts is only 79.75% of them in a maximum level in each planning horizon. As a result, the compared

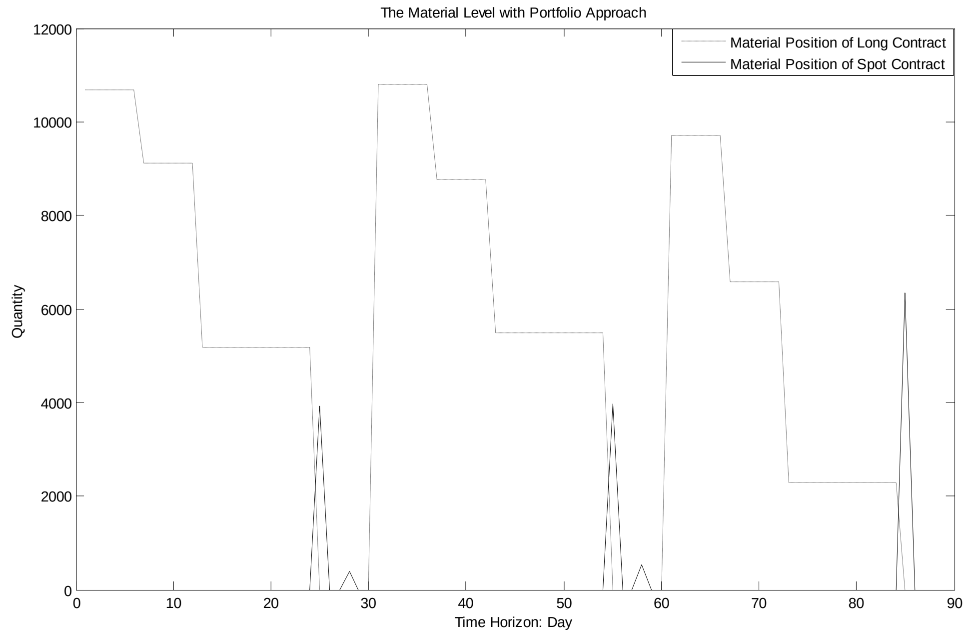

Figure 5. The material level with contract portfolio approach in testing period.

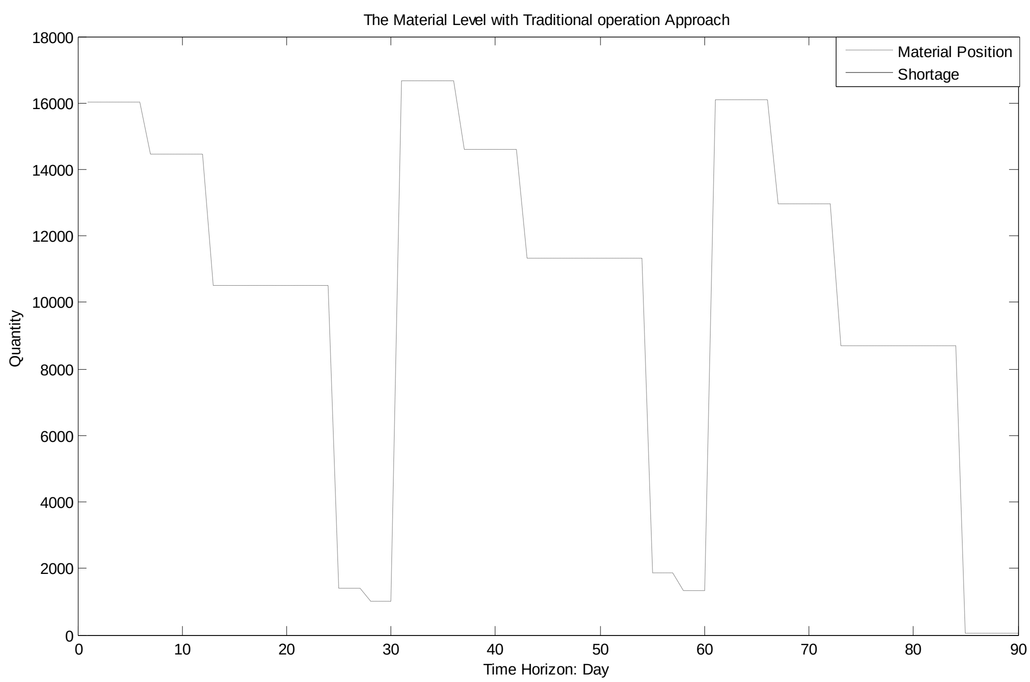

Figure 6. The material level with traditional operation approach in testing period.

results between these two approaches show that the material holding level in each planning horizon with contract portfolio approach is 72.35% of the level with traditional operation approach and resulted in a cost saving of 25.31% from contract portfolio approach.

CONCLUSION

This paper proposes a collaborative production-procurement system with contract portfolio approach to smooth supply disruption incurred from supply chain. This

Table 2. The comparison of contract portfolio approach with traditional operation approach.

Parameter	Contract portfolio approach	Traditional operation approach
Long-term contract	39,720	54,663
Short-term contract level	6,343	0
Short-term contract executed	15,176	0
Total executed amount	54,896	54,896
Average material holding	6,620	9,150
Purchasing costs	5,452,120	7,299,630

model is generated from three steps as mentioned in the work. Firstly, an optimal replenishment policy can be generated through training data. Secondly, based on the optimal replenishment policy and production conditions, to determine the optimal production cycles in a given planning time horizon. By treating inventory as real options, long-term contracts of material can be stably generated from the optimal inventory policy based on the production processes and lead time in contract delivery. On the contrary, a short-term contract can be used to hedge the disruption risks incurred in supply side of supply chain. Finally, a contract portfolio procurement policy can be determined to hedge the supply disruptions with minimal costs. From numerical analysis, firms in supply chain can efficiently and effectively use real options as contract portfolio to minimize their production and procurement costs, in the meantime, provide demand replenishment in a high service level with maximal revenue.

ACKNOWLEDGEMENT

This Industry-Academy Cooperation research work was sponsored by the Ministry of Education, R.O.C. in 2010 under project number 99S-34-029.

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