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# 정보기술을 활용한 공급 사슬의 협업적 조달 시스템에 관한 연구

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# Collaborative Procurement System for IT-Enhanced Supply Chains

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## Abstract

This paper deals with the collaborative procurement process in a two-echelon supply chain that a manufacturing company and a contractor are connected through the information system. The real time information about inventory and production processing becomes available through this information system. We raise two issues related to the collaborative procurement process. First, we propose a VMI(Vendor-Managed Inventory) type of the procurement policy which focuses on the cost minimization for the total supply chain rather than individual companies. Second, based on the simulation study, we demonstrate that a collaborative procurement process is more cost-effective over classical procurement processes such as $(Q, r)$. The result obtained in this paper can be applied to the quantitative evaluation of the cost saving effect when companies build the information sharing based, collaborative procurement system.

***Key Words*** : *Collaboration, Procurement, VMI, Information System, Supply Chain*

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## 1. Introduction

One of the most significant strategies embraced by today's business environment is the outsourcing of manufacturing and logistics. No longer can a company succeed with an approach in which it performs all end-to-end processes through the value chain[11]. That approach provides neither the speed nor the flexibility to respond to the ever-changing demands of today's marketplace. The company must instead focus its efforts on its core competencies, and outsource all non-core aspects of its business to suppliers, distributors, even customers. To do so effectively, it must coordinate, collaborate, and integrate with those outside entities[1].

The e-business is also affecting a company's strategy for sharing information with its partners in the supply chain[12]. Because of decreasing product life cycles and frequent changes of product models, companies are forced to well understand and react to the needs of the customer and to the change of the market. For this reason, the ability to form the effective partnership in a timely manner becomes the key for the success in the market[8]. Such a revolutionary change in the supply chain demands that companies should execute their business process more quickly and frequently[1].

This paper considers procurement process in a two-echelon supply chain that consists of a manufacturing company and a contractor (hereafter we use the term 'partner' instead of contractor to emphasize the importance of collaboration partnership) and studies the beneficial effect of information sharing and collaboration partnership for the supply chain excellency.

The case we present is based on our experience with a fertilizer manufacturing company. The company produces a variety of products based upon orders from customers and the production of certain product is outsourced to its partner. One of the distinct features of this supply chain is that raw material required to produce those products is supplied by the OEM company.

This work is motivated by the fact that the issue of how to utilize information and data in control decision has been less stressed from both the academia and industry than that of IT-infra investment, business process re-engineering, and strategical partnerships. For example, it is commonly observed that plants with ERP system adopt $(Q, r)$ or $(S, s)$ type of classical static policies for inventory management. As shown in this paper, however, a dynamic control of inventory fully utilizing the status information such as demand pattern, production capacity, and delivery process can contribute to reducing supply chain costs dramatically. Obviously, it is possible only when business partners are willing to put the effort for effective business processes, seamless data flow, and collaboration partnerships, etc.

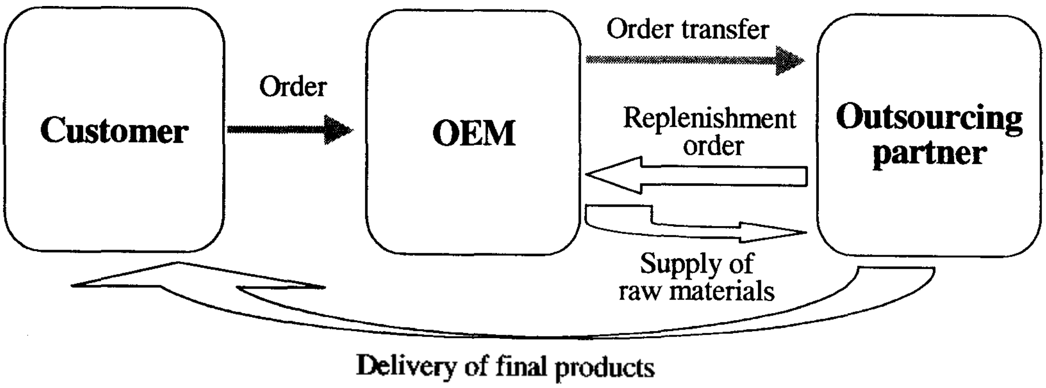
The goal of this paper is to present a real time control policy for collaborative procurement process and to numerically demonstrate the beneficial effect of information sharing. To this end, we present a mathematical model that simplifies our case and perform an extensive numerical analysis with this model. Even though the model of interest does not exactly reflect the real problem, we hope that the insights gained from the numerical investigation will be helpful to develop efficient control policies applicable to the field.

In the next section, we detail the description of the case. Section 3 formulates a mathematical model for the simulation test. In Section 4, we present the result of our computational study for the performance evaluation of our collaborative procurement policy. Finally we state our conclusions in Section 5.

## 2. Case description

<Figure 1> depicts the business process for the supply chain considered in this paper. A customer order is received by the OEM company and transmitted to the partner. Based on the order configuration, the partner produces products by blending raw material with chemical components that are manufactured at its production facility. Upon the production completion, a delivery process is initiated by the partner. Finally, the OEM company activates a billing process and the order is completed. The partner replenishes raw material based on $(Q, r)$ type of policy, that is, it places a replenishment order with size $Q$ units of raw material when the inventory level falls to or below the reorder point $r$.

In recent, the OEM company opened a WEB-based information system for managing outsourcing business efficiently. This




<Figure 1> Business process between the OEM company and outsourcing partner

information system enables the partner electronically to receive customer orders from the OEM company and send raw material replenishment orders. In addition, the OEM company is capable of monitoring in real time order processing status, raw material inventory, and delivery time epoch and issued amounts of final products. Before launching the information system, the partner faced inventory fluctuation and experienced stock-outs unnegligibly, which causes the OEM company to suffer from customer claims due to not meeting the due date. This undesirable situation mainly results from the lack in the information sharing between the OEM company and partner. After opened, the information system is affecting the OEM company's strategy for sharing information with the partner because the product produced by the partner forms a fast growing market.

Even though the information system contributed to resolving communication problem between the OEM company and partner, however, the question of which company should take the responsibility of raw material inventory and how both companies is able to utilize shared information in the replenishment decision. This is a very important but political issue because the partner wishes to place a replenishment order frequently with small order quantities to minimize inventory holding costs whereas the OEM company wants to replenish the partner with large order quantities in order to avoid production delay due to stock-outs.

Based on the above question, we present a replenishment model that has the following features. First, the OEM company is a single decision maker facing replenishment decisions and whose objective is to minimize total system costs. Second, the decision on when to replenish is made dynamically based on the system status such as demand, production, and delivery processes.

The first feature of our model refers to Vendor-Managed Inventory (VMI). VMI is a logistics partnership agreement where the vendor decides on the retailer's inventory levels of products and the appropriate replenishment policies to maintain these levels [10]. No VMI program is known to be successful without some form of information sharing between participants. Although much has been written in the literature about VMI as a concept, there are few quantitative models to support VMI (see [6, 7] for the detailed literature survey about VMI).

Cachon and Zipkin[5] studied a model that both a single supplier and a single retailer are willing to share customer backorder costs and independently choose their base stock policies to minimize their own costs, that is, competitive policies. Based on the numerical comparison with the policy to minimize total system costs, they showed that the competition penalty is sensitive to how customer backorder costs are shared by the supplier and retailer.

Cachon showed that VMI can achieve the minimum of supply chain costs only when both the supplier and retailers participating in VMI contract wish to share the benefits [4]. Aviv and Federgruen[2] also analyzed a VMI model with a single supplier and multiple retailers and numerically showed that VMI in conjunction with information sharing is always more beneficial than information sharing alone.

<Figure 2> displays the business process when a VMI policy is applied to the procurement process between the OEM company and partner. Compared to <Figure 1>, we see that the process for replenishment order placed by the partner is eliminated.

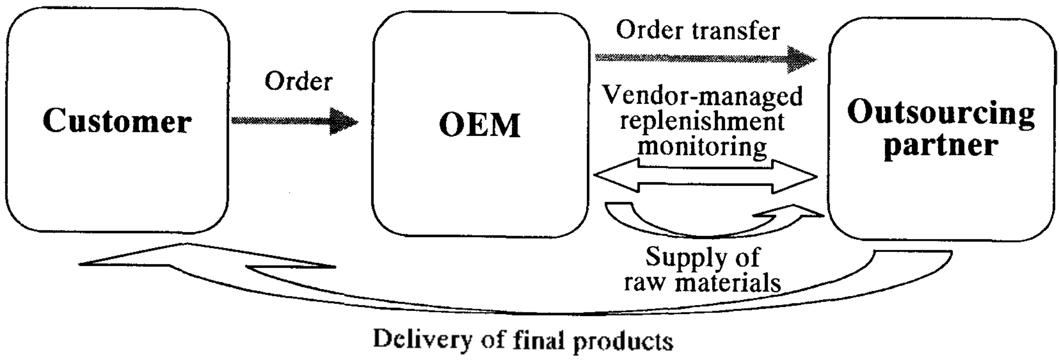
## 3. Simulation model

In this section we present a mathematical model for the simulation study only. The objective of this simulation study is to investigate the beneficial effect of the collaborative procurement policy utilizing real time information.

The company outsources the production of a single class of product to its partner and each customer has an equal order size. Hence, the amount of raw material to process each customer order is the same. Without any loss of generality, one unit of raw material is needed for processing each customer order.

Customer orders arrive at the OEM company according to a Poisson process with rate $a$, and they are immediately transmitted to the partner. Production times for processing each customer order by the partner are exponential random variables with mean $s^{-1}$ and successive productions are independent of all else. Denote the capacity utilization at the partner by $\rho$ (= $a/s$).

For the analysis, we consider the following cost structure. A linear cost is incurred with rate $c$ per unit time for each outstanding customer order. This cost can be viewed as providing an incentive to minimize the weighted flow times of customer orders. In




<Figure 2> Business process with vendor-managed monitoring system

fact, it is an alternative of formulation incorporating the due date constraint into the model. A holding cost is incurred with rate $h$ per unit time for each unit of raw material in inventory at the partner.

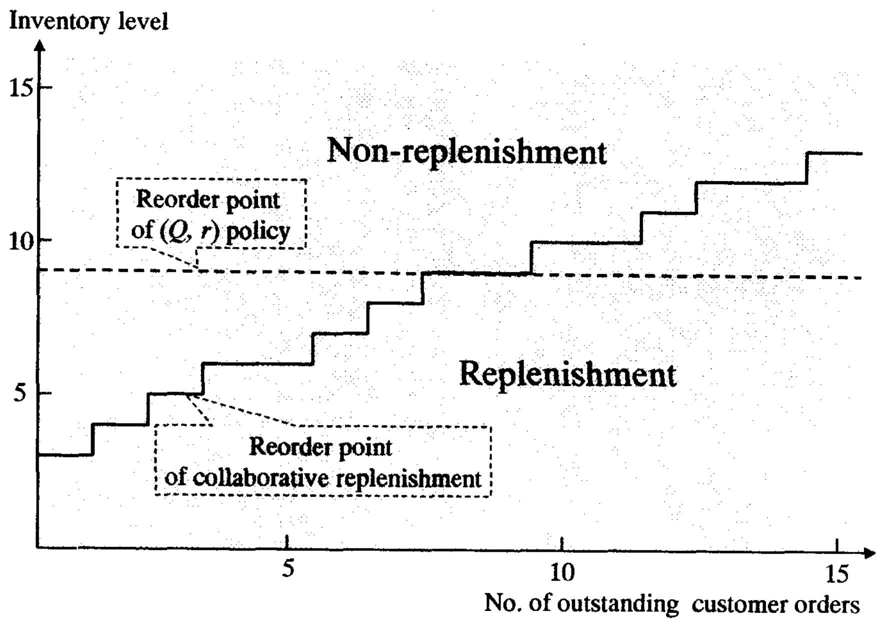
A setup cost $K$ is incurred at each instant a replenishment order with $Q$ units is placed. There is a procurement lead time $L$ for the delivery of the order to the partner. This includes the production time of raw material if inventory is not available in the OEM's plant as well as the transportation time from the company's plant to the partner. The procurement time is assumed to be an exponential variable with mean $\Gamma^{1}$ for the mathematical tractability.

The company makes a replenishment decision in time epochs consisting of customer order arrival, production completion of each customer order, and delivery completion epochs. A policy $P$ specifies, at each decision epoch, whether or not the company (information system) places a replenishment order. We assume that the replenishment process is never interrupted until the completion of transportation process.

Given the procurement policy $P$, the average cost per unit time of the model of interest can be expressed as follows:

$$E[\lim_{T\to\infty}\int_0^T(cx(t)+hy(t)+K\cdot 1\{t\in B^P\})dt/T]$$

where $B^P$ denotes the set of random instances in which the OEM company places a replenishment order under policy $P$. The




<Figure 3> Graphical representation of the collaborative replenishment policy

optimal procurement policy is the one which achieves the minimum in the above equation.

<Figure 3> graphically represents an optimal collaborative procurement policy of an example in <Table 1> in the following section. Unlike $(Q, r)$ policy with a pre-determined and fixed reorder point, our collaborative procurement policy has a reorder point function varied depending on the number of customer orders waiting for production and the inventory level. In other words, the reorder point of our collaborative policy is monotonically increasing as the number of customer orders waiting for production increases and vice versa. We note that this result is quite intuitive.

## 4. Numerical analysis

In this section, we numerically evaluate the optimal collaborative replenishment policy. To compute the average cost per unit time, we use the value iteration method based on the recursive Dynamic Programming (DP) equations. Due to the mathematical complexity, however, we omit the detailed step to draw these equations.

One of the difficulties in finding the optimal policy and cost using value iteration arises from the magnitude of the state space. To resolve this problem we truncate the size of outstanding customer orders and raw material inventory level. Even though the average cost computed by this truncation is not optimal, it can be proven that it is a lower bound on the optimal performance, using a similar argument as in Theorem 1 of Kim and Van-Oyen[9].

We also present the performance of $(Q, r)$ policy that is implemented by the partner for the purpose of justifying the outperformance of VMI type of collaborative procurement policies over static policies in this category of problems. To compute the average cost of $(Q, r)$ policy, the same truncation level as in finding the optimal performance of colla -borative procurement policy is applied here.

The value iteration code is written in C. The stopping rule is given by Proposition 7, Chapter 7 of Bertsekas[3] and the termination criterion is set to $10^{-3}$. The size of outstanding customer orders and raw material inventory level are truncated to 30 and 60, respectively.

When we implement $(Q, r)$ policy, the replenishment quantity is set to the economic order quantity, $\sqrt{2Ka/h}$. The reorder point $r$ is set to the sum of $aL$, the expected number of customer orders that arrive at the company during replenishment process, and the safety stock that is set to a portion of $aL$. This safety stock is required to serve unanticipated demand during the replenishment process. Even though this value should be selected depending on the system parameters, we display numerical result when it is set to 30% of $aL$. However, we note that with different settings of the safety stock level, we could observe a phenomenon similar to the one we present here. In summary, we assume that under $(Q, r)$ policy, the partner immediately requests $Q$ units of raw material to the company if the inventory level drops below $[aL + 0.3 \times aL]$ where $[x]$ is the nearest integer around $x$.

In the following <Table 1-3>, we display the performance of VMI type of collaborative procurement policy for 36 test examples assuming that VMI policy has the same replenishment quantity as $(Q, r)$ policy when testing each example. The item % is defined as the change in percent of the cost given by $(Q, r)$ policy over our collaborative procurement policy.

<Table 1> Performance evaluation of collaborative replenishment policy and $(Q, r)$ policy

| Example | $Q$ | $K$ | $c$ | $h$ | $s$ | $l$ | $a$ | $Opt$ | $(Q, r)$ | % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 11 | 200 | 3 | 1 | 1 | 0.1 | 0.3 | 15.974 | 29.816 | 86.7 |
| 2 | 14 | | | | | | 0.5 | 26.428 | 36.293 | 37.3 |
| 3 | 17 | | | | | | 0.7 | 39.812 | 46.365 | 16.5 |
| 4 | 19 | | | | | | 0.9 | 58.818 | 64.841 | 10.2 |
| 5 | 11 | | | | | 0.3 | 0.3 | 13.410 | 19.774 | 47.5 |
| 6 | 14 | | | | | | 0.5 | 20.962 | 26.396 | 25.9 |
| 7 | 17 | | | | | | 0.7 | 31.326 | 35.069 | 11.9 |
| 8 | 19 | | | | | | 0.9 | 50.815 | 53.465 | 5.2 |
| 9 | 11 | | | | | 1.0 | 0.3 | 12.523 | 16.112 | 28.7 |
| 10 | 14 | | | | | | 0.5 | 18.956 | 22.686 | 19.7 |
| 11 | 17 | | | | | | 0.7 | 27.468 | 30.076 | 9.5 |
| 12 | 19 | | | | | | 0.9 | 44.622 | 46.154 | 3.4 |

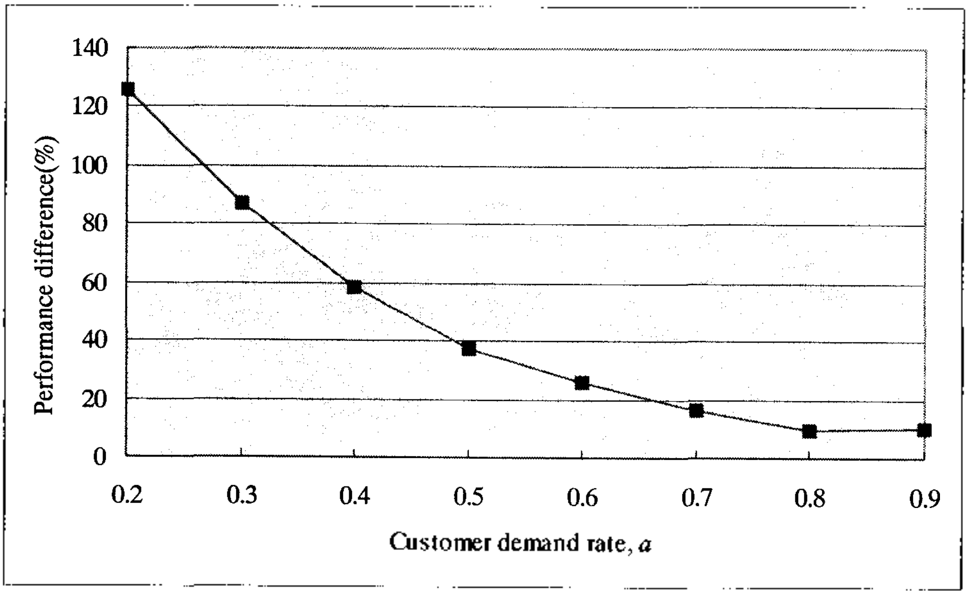
<Table 2> Performance evaluation when outstanding customer order cost increases twice

| Example | $Q$ | $K$ | $c$ | $h$ | $s$ | $l$ | $a$ | $Opt$ | $(Q, r)$ | % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 11 | 200 | 6 | 1 | 1 | 0.1 | 0.3 | 19.302 | 31.126 | 61.3 |
| 2 | 14 | | | | | | 0.5 | 32.816 | 39.665 | 20.9 |
| 3 | 17 | | | | | | 0.7 | 51.678 | 54.842 | 6.1 |
| 4 | 19 | | | | | | 0.9 | 86.700 | 87.912 | 1.4 |
| 5 | 11 | | | | | 0.3 | 0.3 | 15.522 | 21.065 | 35.7 |
| 6 | 14 | | | | | | 0.5 | 25.128 | 29.453 | 17.2 |
| 7 | 17 | | | | | | 0.7 | 39.916 | 42.35 | 6.1 |
| 8 | 19 | | | | | | 0.9 | 72.327 | 73.816 | 2.1 |
| 9 | 11 | | | | | 1.0 | 0.3 | 14.269 | 17.399 | 21.9 |
| 10 | 14 | | | | | | 0.5 | 22.413 | 25.692 | 14.6 |
| 11 | 17 | | | | | | 0.7 | 35.034 | 37.095 | 5.9 |
| 12 | 19 | | | | | | 0.9 | 64.727 | 65.525 | 1.2 |

<Table 3> Performance evaluation when replenishment setup cost increases twice

| Example | *Q* | *K* | *c* | *h* | *s* | *l* | *a* | *Opt* | (*Q*, *r*) | % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 15 | 400 | 3 | 1 | 1 | 0.1 | 0.3 | 20.190 | 35.161 | 74.2 |
| 2 | 20 | | | | | | 0.5 | 31.752 | 43.749 | 37.8 |
| 3 | 24 | | | | | | 0.7 | 46.561 | 56.37 | 21.1 |
| 4 | 27 | | | | | | 0.9 | 59.999 | 78.16 | 30.3 |
| 5 | 15 | | | | | 0.3 | 0.3 | 18.067 | 24.888 | 37.8 |
| 6 | 20 | | | | | | 0.5 | 27.213 | 33.327 | 22.5 |
| 7 | 24 | | | | | | 0.7 | 39.254 | 43.036 | 9.6 |
| 8 | 27 | | | | | | 0.9 | 57.840 | 59.203 | 2.4 |
| 9 | 15 | | | | | 1.0 | 0.3 | 17.116 | 20.912 | 22.2 |
| 10 | 20 | | | | | | 0.5 | 25.104 | 29.646 | 18.1 |
| 11 | 24 | | | | | | 0.7 | 35.273 | 36.879 | 4.6 |
| 12 | 27 | | | | | | 0.9 | 52.875 | 51.019 | -3.5 |

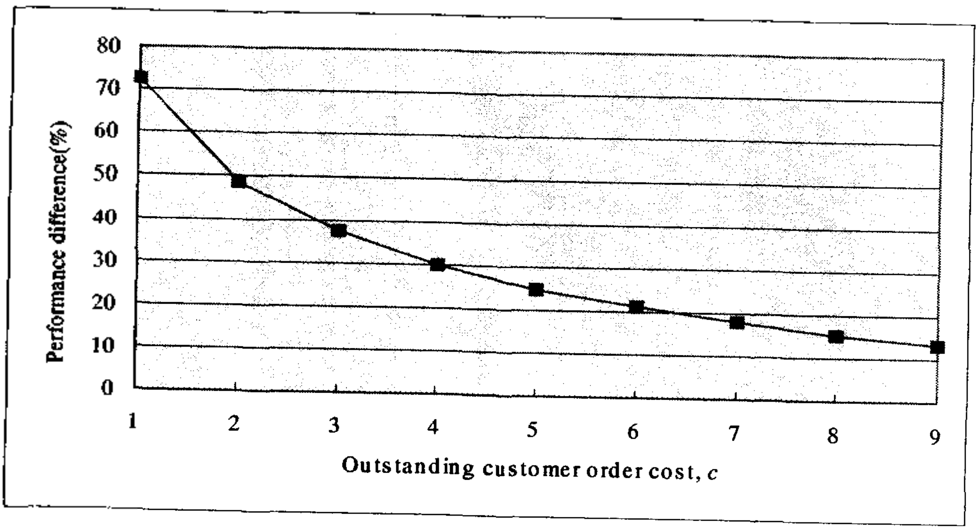
Based on the result of this numerical study, we summarize our observation as follows. The performance difference (%) becomes increasing, that is, our collaborative policy works much better than $(Q, r)$ policy as ⅰ) the capacity utilization becomes low, ⅱ) the production delay cost, $c$, decreases, ⅲ) the expected replenishment lead time increases, and finally, the replenishment setup cost, $K$, decreases.




<Figure 4> Performance difference as a function of customer demand rate, *a*.

The intuition behind the first observation (see also <Figure 4>) is as follows. Given other parameters remain the same, the reorder point function of our collaborative policy (see <Figure 3>) moves to the right as the capacity utilization at the partner decreases. Therefore, the *Replenishment* region below the fixed reorder point $r$ becomes enlarged, which means that the flexibility of the reorder point function contributes to the reduction in costs. On the contrary, if the capacity utilization at the partner increases, the reorder point function of our collaborative policy will move to the left. Due to the reduction in the size of the *Replenishment* region below the fixed reorder point $r$, the flexibility of the reorder point function will be restricted.

The second phenomenon (see also <Figure 5>) can be explained by a reasoning similar to the one described above. As $c$ becomes smaller, it is likely that the reorder point function of our collaborative policy will shift right to avoid frequent replenishment orders. That is, unless enough outstanding customer orders are accumulated, our collaborative policy restricts the action of *Replenishment* while $(Q, r)$ policy allows it below the fixed reorder point $r$ regardless of the number of outstanding customer orders. Therefore, when $c$ is small, the dynamic reorder point given by our collaborative policy greatly contributes to reducing system costs in the *Replenishment* region below the fixed reorder point $r$. When $c$ is large, our collaborative policy places replenishment orders in most of regions below the fixed reorder point $r$ and most of the cost reduction by our collaborative policy occurs in the *Non-replenishment* region above the reorder point $r$. However, this event has low probabilities to occur except for the case




<Figure 5> Performance difference as a function of outstanding customer order cost, $c$.

with high demand rates.

It is also interesting to see that our collaborative policy outperforms $(Q, r)$ policy as the mean replenishment lead time $(L)$ becomes long. A longer replenishment process means that there might be a larger variance in the process. Hence, this result clearly demonstrates the value of dynamic inventory control in the face of the uncertainty in the replenishment process.

## 5. Conclusions

In this paper we studied the procurement process for a two-echelon supply chain in which a company outsources the production of a certain product and the partner procures raw material required in the production from the company. Our goal has been to raise the question of how to efficiently operate the procurement process when players participating in the outsourcing contract shares data and information related to the production and inventory status in real time via the information system.

Two important issues were covered in this paper. First, we focused on the development of the replenishment policy that can achieve the minimum total chain costs rather than minimizing each player's cost. The policy we presented is a special case of VMI in that the information system automatically generates a replenishment signal while monitoring the production and inventory status at the partner. This signal is immediately transferred to the OEM's plant and a replenishment process is initiated there.

Second, we designed our replenishment policy to well reflect outsourcing related data provided by the information system into making replenishment decisions. The resulting policy has a flexible reorder point as a function of the number of outstanding customer orders and the inventory level at the partner. This is the main distinct feature compared to the classical control policies used in many real application which have fixed and pre-defined reorder points.

Numerical analysis performed with designed examples confirmed that our collaborative replenishment policy can be very challenging. In particular, we were able to verify that the collaborative procurement system with information sharing can be beneficial to all supply chain parties. It also draws several interesting observations. Cost savings from the dynamic control of replenishment decisions over the static control can be more significant either as the capacity utilization at the partner becomes lower or as the expected replenishment lead time takes longer.

We believe that the result obtained in this paper can be used as a quantitative model for evaluating potential cost savings and benefits when a company plans to invest on information system or participate in collaboration partnership.

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