The Utilization of Shared Demand Information in a Textile Supply Chain

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Abstract

The focus of this paper is information exploration using alternative utilization models to test how a supply chain responds to demand changes. From the feedback perspective of system dynamics, it is found that the echelon stock policy generates a more complex feedback structure than the installation stock policy; and has different time patterns of inventory adjustment actions. Considering the relative higher cost for small- and medium- size enterprises to adopt advance information technology in our textile supply chain case, this paper further examines the impact of information technology in the echelon stock policy and the installation stock policy. The findings show that information technology investment could be more beneficial for supply chains with the installation stock policy. Finally, this paper mixes the PID controller design concept with the two information utilization models and so suggests further development for information utilization designs.

Keywords: Supply chain, Information sharing; System dynamics; Simulation; Inventory; PID control

Introduction

Information flows along supply chains include sharing downstream information (for example sales, demand forecast, and inventory information) and upstream information (for example order status and production schedule) (Lee and Whang, 1999). This paper focuses on the sharing of demand information to the upstream stages of a supply chain.

The benefits of sharing information have been widely discussed in past research (Lee et al., 2000; Machuca and Barajas, 2004). The bullwhip effect in supply chains can be reduced when there is information sharing downstream of sales and demand forecast (Lee et al., 1997). The benefit that sharing demand information brings to a supply chain is mainly revealed *via* each supply chain member’s inventory management actions. The appropriateness of inventory models in utilizing shared information would impact the extent of benefits possibly resulted from information sharing. However, with the exception of a few papers, most research on information sharing focuses primarily on the parametric optimization of installation stock policy. Though, in Chen’s computational study (Chen, 1998), he assesses the value of centralized demand information in the echelon stock policy and extends the knowledge of how this value is reliant upon system variables; but how supply chains respond to demand changes with different information utilization models is left unexplored. In contrast, rather than setting optimal parameters and analytic inventory models (Yu et al., 2002), the main theme of this paper is to widen our understanding of how different information utilization influences the dynamic adaptation process of a supply chain, and thereby facilitate the design of information utilization policy.

From the feedback perspective, supply chains with an echelon stock policy and an installation stock policy have different feedback structures. Moreover, different feedback structures can lead to different time patterns of response to demand changes (Forrester, 1961). This paper models a textile supply chain using a system dynamics approach to facilitate the feedback analysis of the echelon stock policy and the installation stock policy. The textile supply chain case comprises four small firms whose information technology capability is rather restricted. Supply chain members communicate with each other via fax and telephones. Because information technology capability is critical in the exploitation of the value of shared information, this paper also examines the composite effect of information utilization models and information technology capability in the textile supply chain's response to demand changes. Furthermore, in an attempt to enhance the stability of the time patterns of the supply chain's inventory adjustment actions, the two information utilization models - the echelon stock policy and the installation stock policy - are also tested using the addition of a proportional-integral-derivative (PID) controller design. A PID controller is the most common design in control theory. Control theory has been extensively applied to production-inventory systems in the past, and in supply chain management more recently (Axsater, 1985). The PID controller has been proved to be useful in the design of efficient production-inventory systems (Orgeta and Lin, 2004).

The remainder of this paper is organized as follows. Background knowledge of the textile supply chain case is introduced and the interrelationships among supply chain members are briefly described. Supply chains with an installation stock policy and an echelon stock policy are then simulated and the results analyzed. The role of information technology is addressed; and the implications of information technology investment with regard to the value of information sharing are discussed. Finally, the PID controller design is applied to the two information utilization models; and tested to demonstrate the enhancement of the supply chain's stability. The paper concludes with a summary of the value of this work, and an indication of possible directions for future developments.

How the textile supply chain case operates

Figure 1 depicts the information flow and material flow in the textile supply chain case. Firm A centrally controls the operation of the supply chain. The operation of the supply chain is initiated by the original equipment manufacturer's (OEM) orders for accessories (mainly for hats, from abroad). To satisfy OEM orders, the production process includes yarn spinning, weaving, finishing and dyeing, and cutting and sewing. Firm A receives the OEM orders and retains the last phase of the production process (cutting and sewing). Firm A then outsources the rest of the production process to upstream supply chain members. The finishing and dyeing activities are outsourced to firm B and weaving activity is outsourced to firm C.

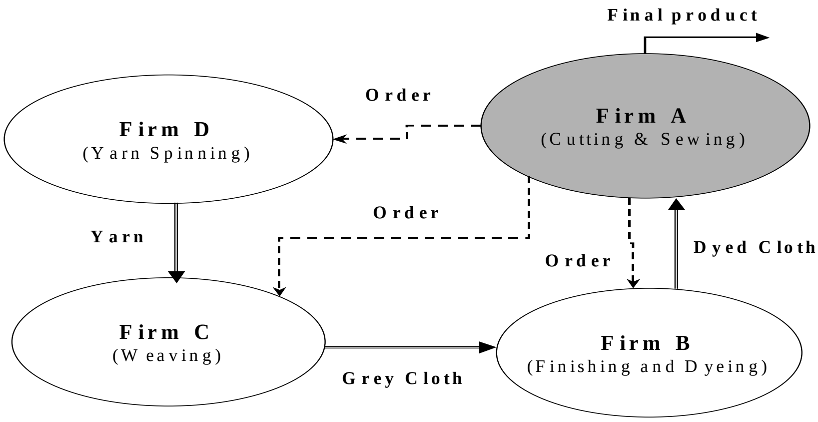

Figure 1 A textile supply chain case

Firm A is responsible for all kinds of inventory along the supply chains. Categories of inventory include yarn materials, grey cloths, and dyed cloths. Firm D supplies the yarn materials to firm C for weaving tasks. At the location of firm C, yarns are transformed into grey cloths and then shipped to firm B for further dyeing and finishing. Inventory of yarn is stored at the location of firm C and the inventory of grey cloths is stored at the location of firm B. Firm A keeps the dyed cloths at its warehouse in preparation for future OEM orders.

All inventory status information is sent to firm A, who then decides the order quantity of yarns and the amount of weaving, dyeing and finishing. Firm A owns all inventories, though they are distributed in firm B and firm C. Firm A starts cutting and sewing only when an OEM order is received. In other words, the production system in this case can be divided into two stages: one stage is to maintain various kinds of inventory with a build-to-stock policy; and the other stage is based on the build-to-order policy that starts cutting and sewing activities when orders are received. The employment of build-to-stock policy in the first stage reflects the long lead time of yarn purchasing and transportation (10 days) and the time necessary for gray cloth sewing (20 days). In this paper, we focus on the build-to-stock activities and discuss possible models to utilize shared information along the supply chain.

The textile supply chain applies the echelon stock policy to manage yarns, grey cloths, and dyed cloths. Inventory replenishment for yarns and grey cloths considers the downstream stages' direct and indirect inventory requirements. Firm A manages the dyed cloth inventory with (s, Q) model and the grey cloth inventory and the yarns with (R, S) model, respectively. In the (R, S) system every R units of time (periodic review) enough is ordered to raise the inventory level to the order-up-to level S. In the (s, Q) system a fixed quantity Q is ordered whenever the inventory level drops to the reorder point s or lower. In this paper, the difference between (s, Q) model and (R, S) model is not discussed, for the model built is at a higher aggregate level which focuses on how to utilize shared information, rather than how to decide the discrete order quantity or timing. The time required from order to delivery of yarns is approximately ten days. The average weaving time to produce grey cloth is approximately twenty days; and the dyeing and finishing time is some two days. The forecasting period of OEM orders is approximately 45 days. Yarns are measured by weight (kilograms). Grey cloths and dyed cloths are measured by yards. The transfer rate between the yarns and cloth is approximately eight kilograms to one yard.

Feedback structures of the echelon stock policy and the installation stock policy

Based on information previously discussed (above) and information derived from interviews with firm A, B, and C, a system dynamics model was developed. Because the mathematical representation of the system dynamics model is too complex to accentuate the structural difference and different information utilization policies, this paper uses the causal loop diagram to represent important feedback structures.

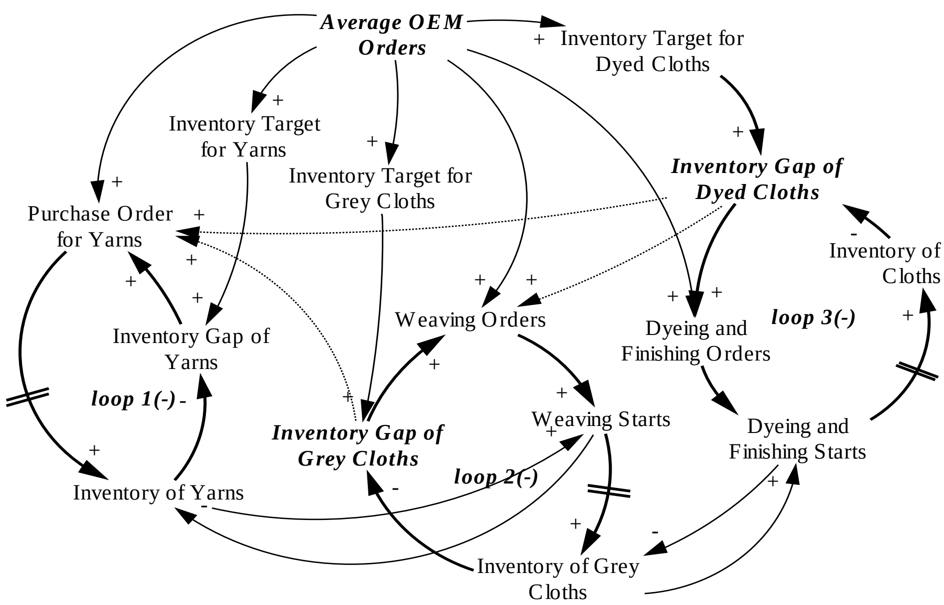

Figure 2 Feedback structure with the echelon stock policy

Figure 2 is the simplified feedback structure of the original supply chain based on the echelon stock policy. Loop 1, loop 2, and loop 3 are three major negative loops for the adjustment of yarn inventory, grey cloths inventory, and dyed cloths inventory. The adjustment goals of these loops are determined by the average OEM orders and inventory gaps of all downstream inventories. Firm A calculates the direct yarn requirements in firm C for the input for weaving process and the indirect yarn requirements in firm B for dyeing and finishing. The same logic also applies to the weaving orders and the dyeing and finishing orders.

According to the above description, we can identify three additional loops related to the adjustment of yarn inventory and grey cloths inventory. The impact of the three loops appears only when the yarn inventory or the grey cloth inventory are insufficient to constrain the start of weaving or the dyeing and start of finishing processes. These loops are:

Inventory of Yarns→Weaving Starts→Inventory of Grey Cloths→Purchase Order for Yarns→Inventory of Yarns;

Inventory of yarns→Weaving Starts→Inventory of Grey Cloths→Dyeing and Finishing Starts→Inventory of Dyed Cloths→Inventory Cloths→Inventory of Dyed Cloths →Purchase Order for Yarns→Inventory of Yarns;

Inventory of Grey Cloths→Dyeing and Finishing Starts→Inventory of Dyed Cloths →Inventory Gap of Dyed Cloths→Weaving Orders→Weaving Starts→Inventory of Grey Cloths

Among these three loops, the first two loops would facilitate the adjustment of yarn inventory, and the last one is for the adjustment of grey cloths. As discussed, the three loops are implicit loops with an influence only when the amount of yarn inventory or the amount of grey cloths is insufficient to support the desired planned weaving orders or the dyeing and finishing orders.

In contrast to the echelon stock policy is the feedback structure shown in Figure 3 which is much simpler. Figure 3 is the modified textile supply chain with the installation stock policy. In figure 3, the OEM order is still shared among supply chain members. The adjustments of yarns, grey cloths, and dyed cloths are based on OEM orders. However, unlike the echelon stock policy, the adjustment goals of loop 1, 2, and 3 in Figure 3 comprise only the on-site inventory status. Furthermore, the three implicit loops in the echelon stock policy do not exist in the installation stock policy.

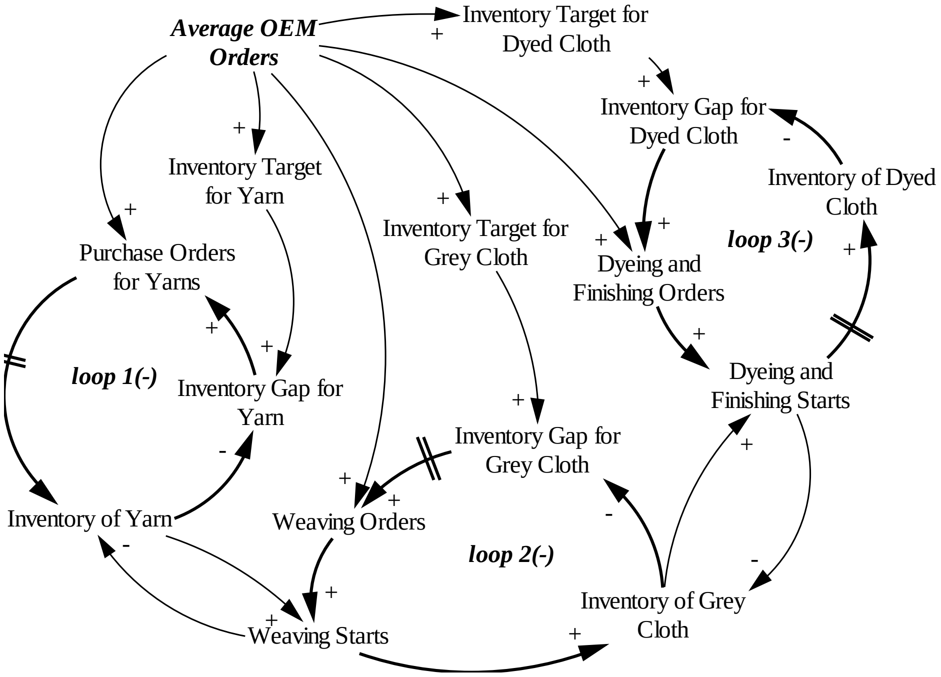

Figure 3 Feedback structure with the installation stock policy

According to the above discussion, it is found that the feedback structure of the echelon stock policy can be simplified to three major adjustment loops and three implicit loops for inventory adjustments. Moreover the core structure of the installation stock policy is also composed of three inventory adjustment loops for yarns, grey cloths, and dyed cloths. The simplified structures of the two inventory models are different in the elements of their goals seeking, but similar in the nature of the delayed negative loops which would cause the supply chain's instability in the pursuit of goals. How the two inventory models with these differences and similarities influence the textile supply chain's response to demand changes, is further analyzed and discussed in the next section.

Feedback analysis with different information utilization models

To accentuate the different time patterns generated by different feedback structures, we simplify the OEM orders received by firm A to be a rate that consumes 400 yards of dyed cloths at the beginning of every day. At day sixty, OEM orders is set to increase suddenly to a level that needs 440 yards of dyed cloths; and maintains the requirement level subsequently. In response to such change, firm A adjusts its purchase orders, weaving orders, and dyeing and finishing orders to make the inventories of yarns, grey cloths, and dyed cloths stay at the new safety stock level.

The simulated behavior of the purchase of yarns and time patterns of the amount of yarn inventory based on the echelon stock policy and the installation policy is shown in Figure 4. In Figure 4, the curve that oscillates more dramatically is based on the installation stock policy, whilst the other is based on the echelon stock policy. From Figure 4, it can be shown that the purchase order of yarns based on the installation stock policy is surprisingly turbulent; and the response based on the echelon stock policy is relatively stable. With reference to Figure 2 and Figure 3 (the feedback structure of the installation stock policy): both information utilization models utilize shared OEM orders and seek to achieve the ultimate stable state of the supply chain. The infamous bullwhip effect that may derive from the downstream stage's distorted information can be reduced dramatically. However, the essence of a negative loop with delays still makes the adjustment actions of yarns oscillate to a greater extent. In relative terms, the impact of time delays is not so great in the echelon stock policy, for the composite goals of the adjustment loop of yarn inventory has taken the downstream stages' inventory status into account in advance.

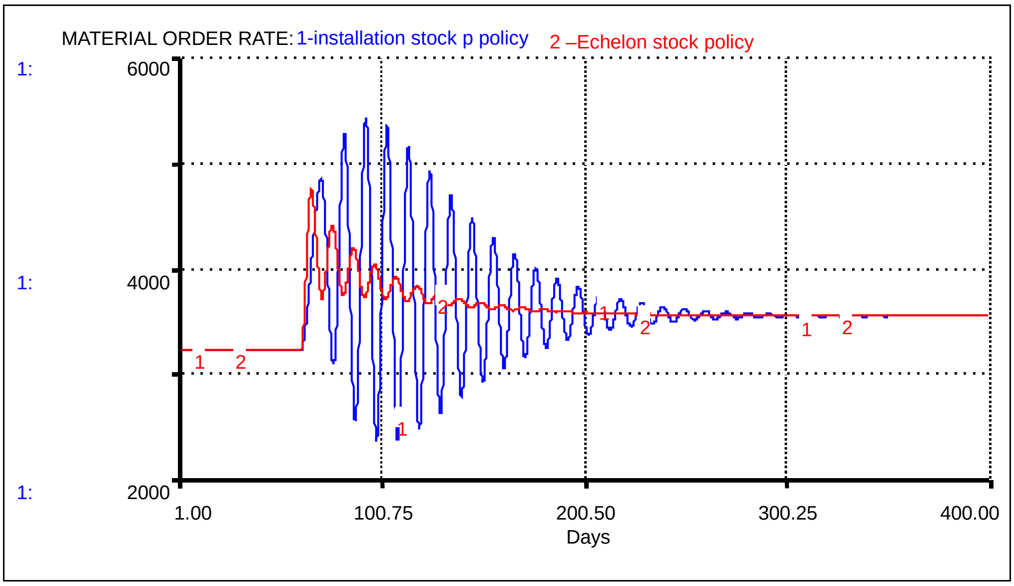

Figure 4 Time patterns of purchase rate of yarns

Unlike the echelon stock policy, the installation stock policy ignores the downstream stages' requirement for yarns. The adjustment of yarn inventory, considers the supply chain's final stable status based on the OEM orders, and overlooks the temporary yarn requirement when downstream stages respond to OEM order changes. The result of ignorance of the downstream stages' of yarn requirement manifests as the amplification of oscillations when those downstream requirements are reflected later on the reduction of yarn inventory. The problem of time delays in the adjustment of yarn inventory is more serious, and thus makes the oscillation more turbulent in the installation stock policy than in the echelon stock policy.

The different feedback structures in the two information utilization models generate different time patterns of yarn inventory; as depicted in Figure 5. In Figure 5, yarn inventory in the installation stock policy reduces more than that of the echelon stock policy, which is reacting to the late adjustment of purchase rate. Because the adjustment of grey cloths has the same time pattern characteristics as yarns, we skip this aspect of the discussion in this paper.

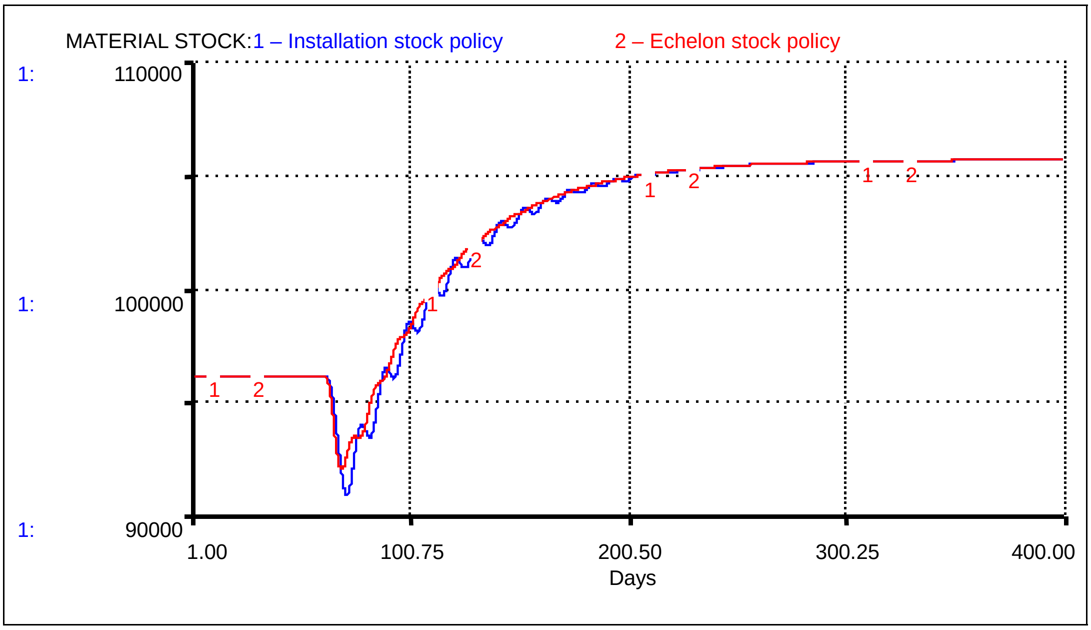

Figure 5 Time patterns of yarn inventory

In summary, even with shared demand information, time delays in the adjustment of inventory to changes in demand, unavoidably cause inventory adjustments to oscillate. The adjustment loop of the echelon stock policy, whilst incorporating more complex adjustment goals, can generate more stable response patterns than the installation stock policy. The problem of time delays in the negative loops of inventory adjustments is deepened in the installation stock policy, as it does not take into consideration the material requirements from the downstream stages.

Composite effect of information utilization and information technology in information sharing

Information technology plays an important role in the reduction of the time delays that cause oscillation problems. The most commonly used information technologies for supply chain management – including EDI, POS, ERP, SCM, and CRM – exchange data between firms via the Internet. In this textile supply chain case, firm A is wondering how much the supply chain, which is composed of small firms, can gain from any information technology investment. Current information systems used by members of the supply chain are simplistic software: such as spreadsheets and word processing. Based on the analysis of information utilization models, this section examines the composite effect of information technology and information utilization models, and so suggest which information utilization model can benefit from any IT investment.

In the textile supply chain case, information delays include: clerk ordering arrangement time, order processing time, and batch processing delay. With intra-firm and inter-firm information systems, the information processing and transmission delays can be limited to ten days; that is one third of normal order-to-delivery time in the supply chain. To explore the composite effect of information technology and information utilization, we assume that the information about the purchase order of yarns, weaving order of grey cloths, dyeing and finishing orders of dyed cloths, and inventory status information are processed in real time and transparent to all supply chain members.

Figure 6 and Figure 7 are simulation results for the echelon stock policy and the installation stock policy. In both Figures, there are two curves indicating the time patterns of purchase orders with and without information technology investment. In Figure 6, it shows that reduction of order to delivery time can effectively improve the oscillations in the adjustment actions of yarn inventory. Although it needs time for action in yarn adjustment to create the new stable equilibrium, the oscillation pattern seen in Figure 4 is greatly reduced and, eventually, eliminated. The improvement brought about by IT is even more dramatic in the installation stock policy that is shown in Figure 7. The large amplifying oscillations in the installation stock policy are greatly improved. The improved time patterns in the installation stock policy due to the reduction of time delay in the negative loop of yarn adjustment, is as good as the improved pattern in the echelon stock policy.

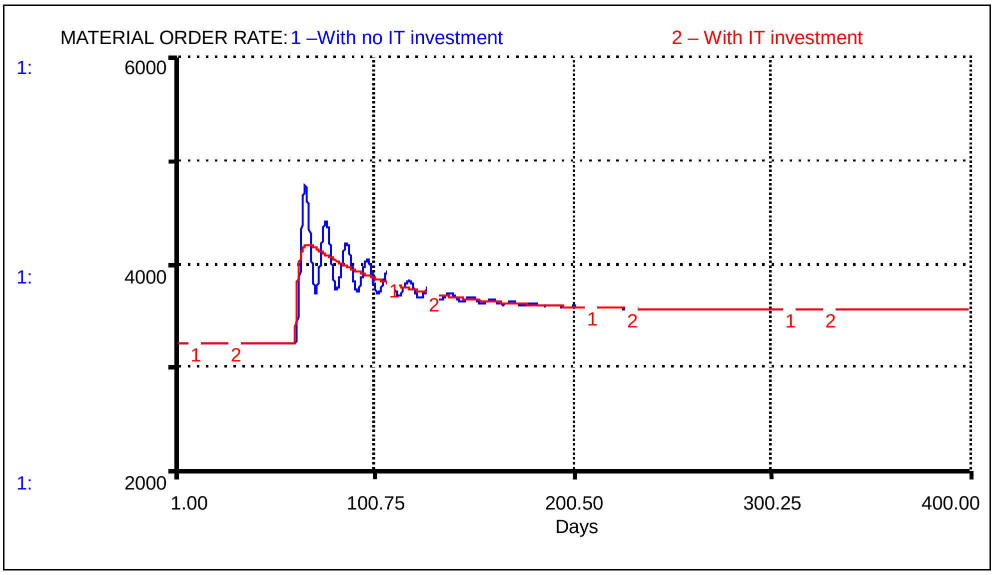

Figure 6 Comparative simulations about IT investments in the echelon stock policy

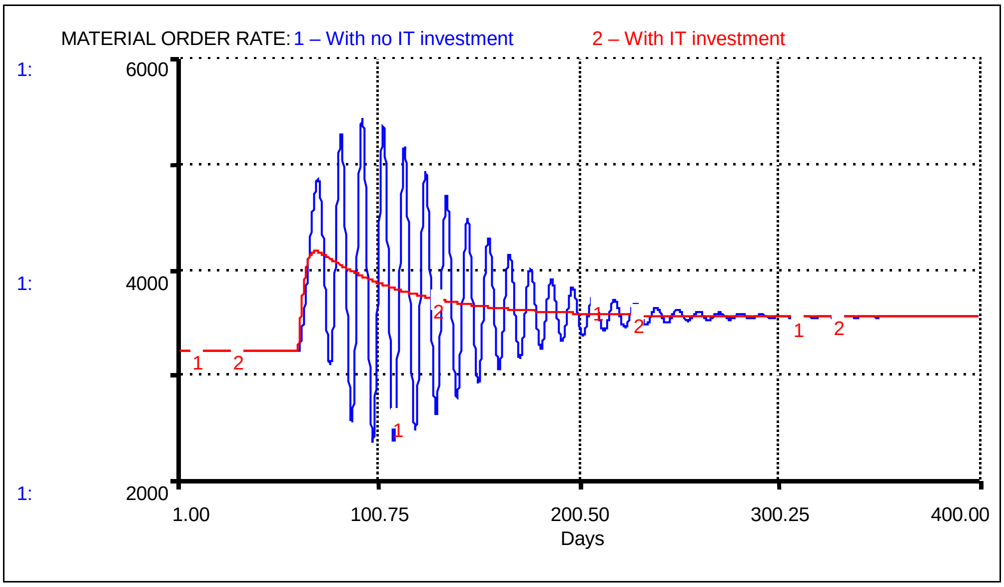

Figure 7 Comparative simulations about IT investments in the installation stock policy

From these (above) observations, we derive some interesting propositions regarding information technology investment issues for any information sharing policy. First, information technology can, indeed, increase the stability of supply chains. Furthermore, the extent that information technology benefits a supply chain varies with different information utilization models. The advantage of information technology investment in the installation stock policy is greater than in the echelon stock policy. Second, for a supply chain that is considering how to improve its stability in response to demand changes, both the redesign of information utilization models and the elimination of information related delays can be effective solutions. The elimination of information related delays could be effective in both of the echelon stock policy and the installation stock policy; and even more beneficial than the redesign of information utilization models. This proposition is consistent with the statement that, the importance of the reduction of lead-time is higher than the refinement of inventory models; which is consistent with previous research (Cacheon and Fisher, 2000).

An alternate design of information utilization model-based on the PID controller concept

After evaluating the difficulties for firm A to persuade other supply chain members to adopt information systems and form a tightly coupling supply chain, we suggested that firm A to improve the stability of the supply chain: following the redesign of the information utilization models. In addition to the echelon stock policy and the installation stock policy, we further applied the PID controller concept to the echelon stock policy and the installation stock policy to see if the stability of the supply chain could be increased, as occurred with information technology investment. Control theory has been applied to the design of production-inventory systems in the past, and in supply chain management in recent years. A PID controller is one of the most common types of controllers and has been tested for application in the production and inventory system. We embedded the PID controller in the echelon stock policy and the installation stock policy and replaced the (R, S) model used by the textile supply chain.

Combined with the PID controller, and with no additional information technology, Figure 8 and Figure 9 demonstrate that the simulated results of purchase orders based on the echelon stock policy and the installation stock policy. In both Figures, there are two curves identical to Figure 6 and Figure 7. The third curve is generated with a PID controller design.

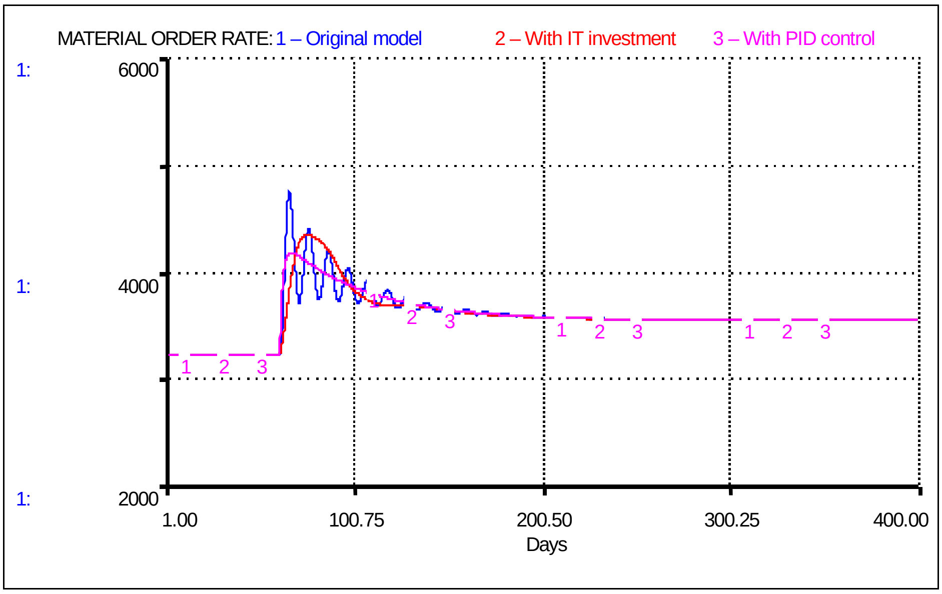

Figure 8 Purchase order with PID controller in the echelon stock policy

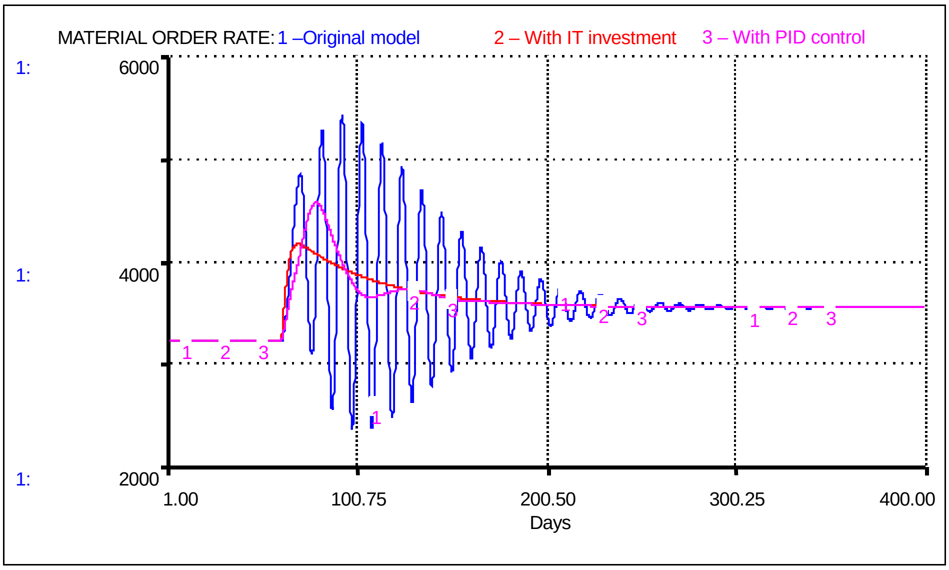

Figure 9 Purchase order with PID controller in the installation stock policy

From Figure 8 and Figure 9, it can be seen that the supply chain can be more stable with a PID controller than the traditional (R, Q) model, in both kinds of information utilization models. Although the improvement to the oscillations are not so great as the supply chain with information technology, the oscillations of purchase rates have been reduced dramatically with the addition of a PID controller design. To our textile supply chain members who are not willing to invest in information technology, they can consider the PID controller design to be combined with information utilization models.

Conclusions and Possible Future Direction for Research

How to utilize shared information is critical to the exploitation of its value. Rather than setting optimal parameters and considering analytic inventory models as the work of Yu, Yang and Cheng (2000), this paper focuses on how *different* information utilization influences the dynamic adaptation process of a supply chain when responding to demand changes; and thereby facilitate the design information utilization policy. The paper analyzes the feedback structures of two basic inventory models: first, the echelon stock policy and second, the installation stock policy. The paper discusses a textile supply chain model using a system dynamics approach. Through a series of simulations and experiments, we have the following findings. First, the echelon stock policy generates a feedback structure that reduces the time delay problems in supply chains in a more efficient way than the installation stock policy; thus improving the stability along supply chains. Second, information technology investment is more beneficial in supply chains with the installation stock policy than supply chains with the echelon stock policy. Third, both the echelon stock policy and the installation stock policy can perform better when combining with a PID controller design. Experimental testing indicates that the supply chain's stability increased with this combination.

For the theoretical development of supply chain management knowledge, this paper develops our understanding regarding the essence of feedback information utilization models and the relationships between inventory utilization models and the dynamics of supply chains. To practitioners involved in the supply chain collaborations, this paper answers some critical questions arising from issues of information sharing practices, such as how to exploit the value of shared information. It also addresses questions such as: 'Is information technology investment necessary in information sharing?' 'Is there any alternative to improve the performance the information utilization chosen?'

In summary, there are three important contributions arising from this paper. First, we suggest that an appropriate design of information utilization model is critical in the exploitation of the value of shared demand information. Different information utilization designs generate different feedback structures and thus influence the stability of the supply chain. Second, the importance of information technology varies with different information utilization models. In the installation stock policy, information technology investment can bring more benefit to the supply chain than in the echelon stock policy. Third, a PID controller design could be used in the information utilization model to increase a supply chain's stability in response to demand changes. Future research can develop the application of the control theory concept and so design improved information utilization models to exploit the value of shared information.

References

Axsater, S. (1985). Control theory concepts in production and inventory control. *International Journal of Systems Science* **16**, 161-169.

Cacheon, G.P. and Fisher, M. (2000) Supply chain inventory management and the value of shared information. *Management Science* **46**, 1032-1048.

Chen, F. (1998). Points, and the value of centralized demand information. *Management Science* **44**, 221-234.

Forrester, J.W. (1961) *Industrial Dynamics*. MIT Press, MA.

Lee, H. and Whang, S. (1999) Decentralized multi-echelon supply chains: incentives and information. *Management Science* **45**, 633-640.

Lee, H.L., Padmanabhan, V. and Whang, S. (1997) Information distortion in a supply chain: the bullwhip effect. *Management Science* **42**, 546-558.

Lee, H.L., So, K.C. and Tang, C.S. (2000) The value of information sharing in a two-level supply chain. *Management Science* **46**, 626-664.

Machuca, J.A.D. and Barajas, R.P. (2004) The impact of electronic data interchange on reducing bullwhip effect and supply chain inventory costs. *Transportation Research Part E* **40**, 209-228.

Orgeta, M. and Lin, L. (2004) Control theory applications to the production-inventory problem: a review. *International Journal of Production Research* **42**, 2303-2322.

Yu, Z., Yan, H. and Cheng, T.C.E. (2002) Modeling the benefits of information sharing-based partnerships in a two-level supply chain. *Journal of the Operational Research Society* **53**, 436-446.