Information Sharing to Reduce Fluctuations in Supply Chains: A Dynamic Feedback Approach

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Supply chain inventories are prone to fluctuations and instability. Small variations in end item demand create oscillations that amplify throughout the chain, also known as bullwhip effect. In this research we try to understand the underlying structure that generates bullwhip effect, and try to explore the effect information sharing on this behavior by using dynamic system simulation. Analysis shows that (i) one of the root causes of bullwhip effect is independent demand forecasting performed at each stage of the supply chain and (ii) demand sharing can reduce but not eliminate the bullwhip effect.

Keywords: System dynamics, bullwhip effect, supply chain, information sharing

Introduction

Supply chain inventories are prone to fluctuations and instability: Even small variations in end item demand create oscillations that amplify throughout the chain, also known as the bullwhip effect (Lee et al. 1997, Sterman 2000). It is shown that order batching, demand signal processing and lead times cause bullwhip effect even if each agent applies locally optimal ordering policies (Lee et al. 1997).

Supply chain management literature focuses on coordination policies that employ information sharing in order to reduce the bullwhip effect. Chen et al. (1998) argues that centralizing demand information could significantly reduce bullwhip effect. Information sharing can be in the form of end item demand sharing, inventory information sharing, and forecast sharing. Xu et al. (2000) reports that demand and forecast sharing is effective in reducing order fluctuations and safety stocks.

The purpose of this research is twofold: (1) to understand the underlying structure that generates inventory fluctuations and bullwhip effect; and (2) to explore the effects of the key information sharing mechanisms suggested by the supply chain management literature on this behavior. Dynamic feedback modeling is used for this purpose.

Model Structure

We have considered three-stage supply chain system consisting of identical agents where each agent orders only from its upper stage. An agent ships goods immediately upon receiving the order if there is sufficient on-hand inventory. Orders may be partially fulfilled, and unfulfilled orders are backlogged. Shipped goods arrive with a transit lead-time. Last stage gives orders to an infinite source. This model can represent an uncapacitated producer-wholesaler-retailer.

Each stage continuously observes its inventory position and gives orders according to a specific ordering policy. Inventory Position of a stage is sum of Local Inventory, In Transit goods from upper stage, Backlog at upper stage minus Backlog at that stage ($IP_i = LI_i + IT_i + BL_{i+1} - BL_i$). Each stage estimates its demand based on orders received from lower stage by using simple exponential smoothing.

The stock-flow diagram of the model is shown in Figure 1. The uppermost stage in the figure represents stage three – the producer.
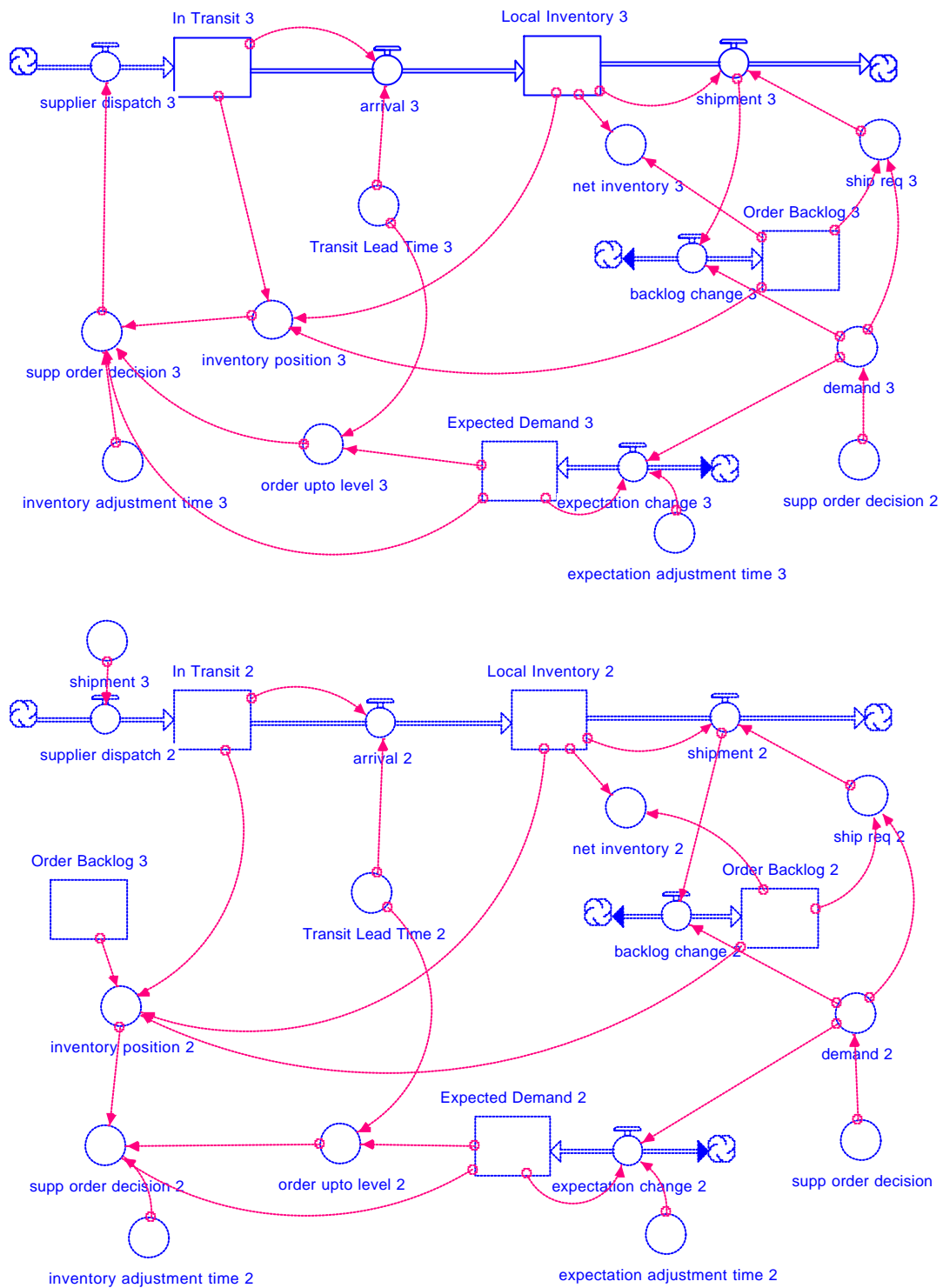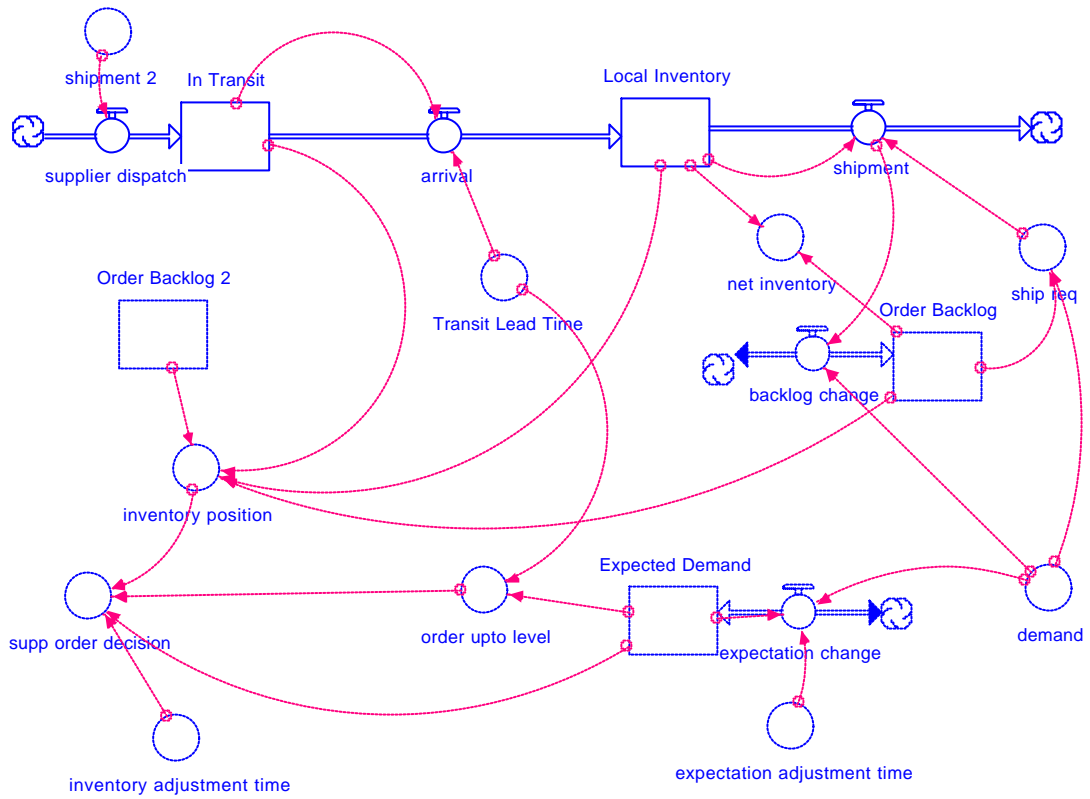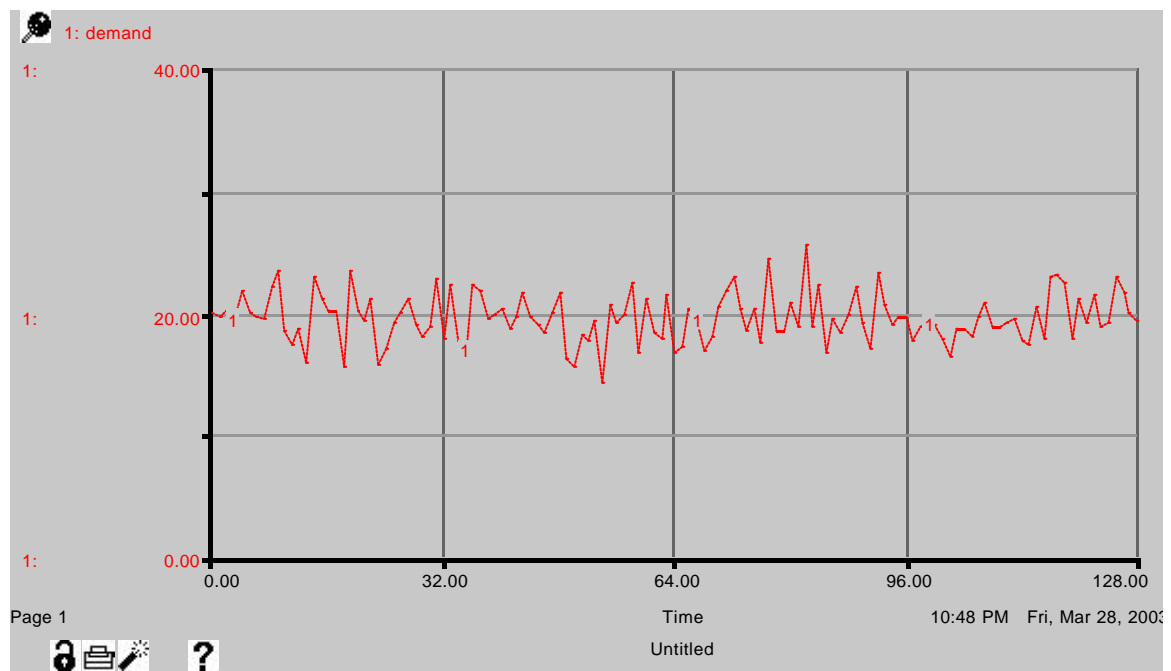
Figure 1 "Stock-Flow Diagram of Three Stage Supply Chain"

Demand Pattern

Random and autocorrelated demand patterns are used in simulation runs. For random demand pattern iid Normal (20,2) is employed (Figure 2). Exponential smoothing of iid normal is used to obtain demand with various autocorrelations (e.g. AC=5, AC=10).

Figure 2 "End Item Demand"

Ordering Policies

Three basic single stage inventory management policies are tested with the supply chain model: Order-up-to-S policy, System Dynamics (SD) Policy (anchor-and-adjust policy widely used in System Dynamics literature), and (s,S) Policy. Since all stages are identical, all stages use the same policy with the same parameters. Each stage makes its ordering decision independent of the other without considering the supply chain. In other words, each applies a policy that locally optimizes its own inventory problem.

Order-up-to S Policy

Order-up-to S Policy is the well-known base stock policy where an agent orders the quantity needed to bring its inventory position back to a base stock level (S) whenever it falls below S.

The associated order equation is the following:

Order = max(((order_upto_level-inventory_position)/inventory_adjustment_time)
        +Expected_Demand,0)

Where,

order_upto_level(S) = (Transit_Lead_Time + K)*Expected_Demand
K, Constant
Expected_Demand=Exponentially smoothed demand for the stage (remember that
                $demand_i = order_{i-1}$)
inventory_position=($IP_i = LI_i + IT_i + BL_{i+1} − BL_i$)
inventory_adjustment_time=1

In this model the important point is that the order-up-to level (S) is updated each period as the expected demand is updated. The resulting behavior can be seen in Figure 3.
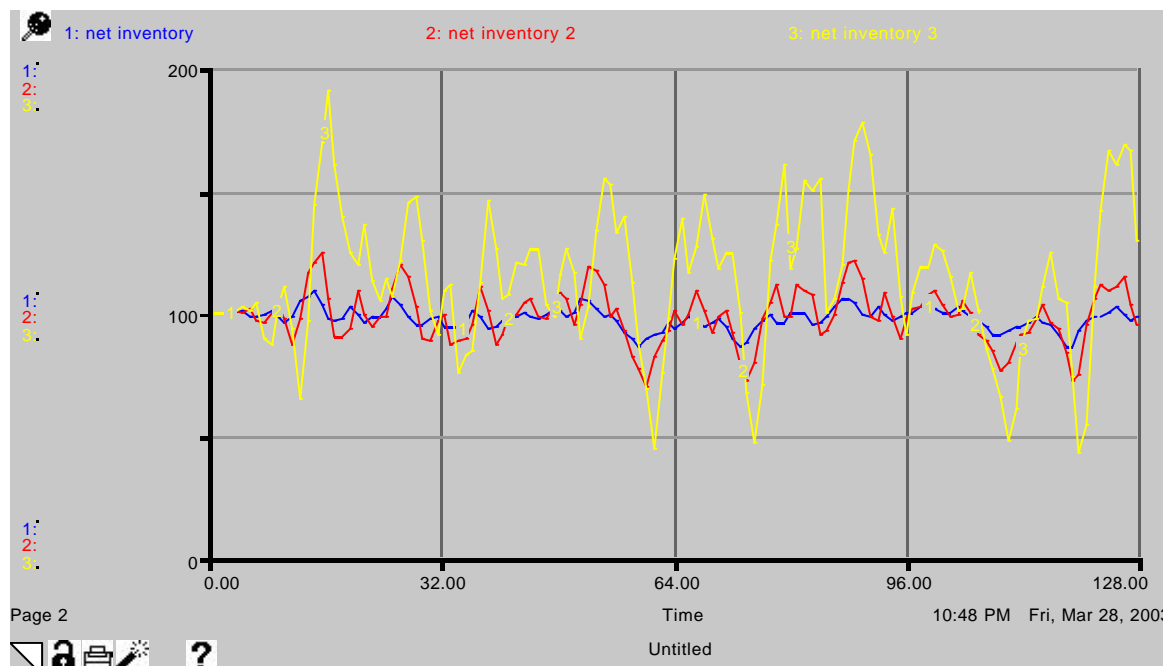

Figure 3 "Simulation Result for Order-up-to S Policy"

SD Policy

System Dynamics (SD) Policy is the anchor-and-adjust policy widely used in System Dynamics literature in which local inventory is tried to be kept constant at a desired level.

The associated order equation is the following:

$Order = max(((desired\_inventory-inventory)/inventory\_adjustment\_time) +$
$\qquad ((desired\_supply\_line-supply\_line)/supply\_line\_adjustment\_time)$
$\qquad +Expected\_Demand,0)$

Where,

$desired\_inventory,\ Constant$
$inventory = Local\ Inventory - Backlog = LI_i - BL_i$
$desired\_supply\_line = Lead\_Time * Expected\_Demand$
$supply\_line = In\_Transit + Backlog\ (at\ upper\ stage) = IT_i + BL_{i+1}$
$inventory\_adjustment\_time = supply\_line\_adjustment\_time = 1$
$Expected\_Demand=Exponentially\ smoothed\ demand\ for\ the\ stage$

Note that, in this model, although desired supply line is adjusted according to expected demand, desired inventory is kept constant. The behavior of the supply chain can be seen in Figure 4.
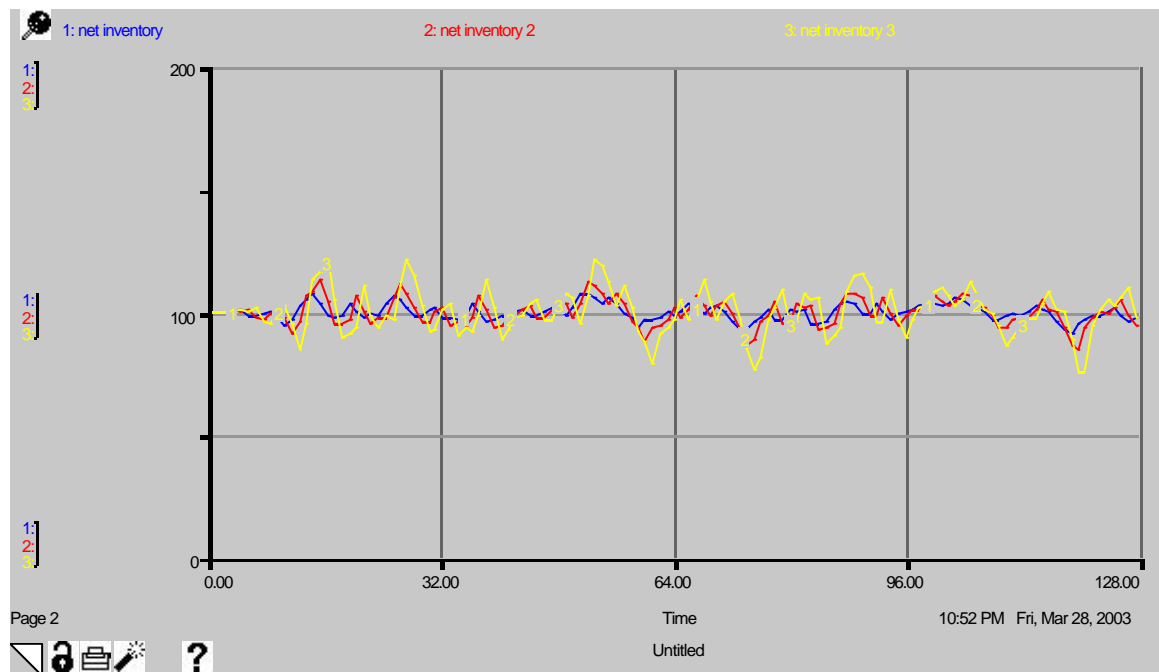

Figure 4 " Simulation Result for SD Policy"

(s,S) Policy

(s,S) Policy is the single stage continuous review policy where an order is placed to raise the inventory position to order-up-to level S whenever the inventory position drops to the reorder point s or lower.

The order equation is the following:

$if\ inventory\_position <=\ min\_inventory\ then$
$\qquad Order = (order\_upto\_level-inventory\_position)/inventory\_adjustment\_time$

else

   Order = 0

Where,

min_inventory (s)= std deviation of forecast errors of lead time demand, Constant for the purpose of simulation

order_upto_level (S)= min_inventory+(Expected_Demand*q)

q, Constant

inventory_adjustment_time=1

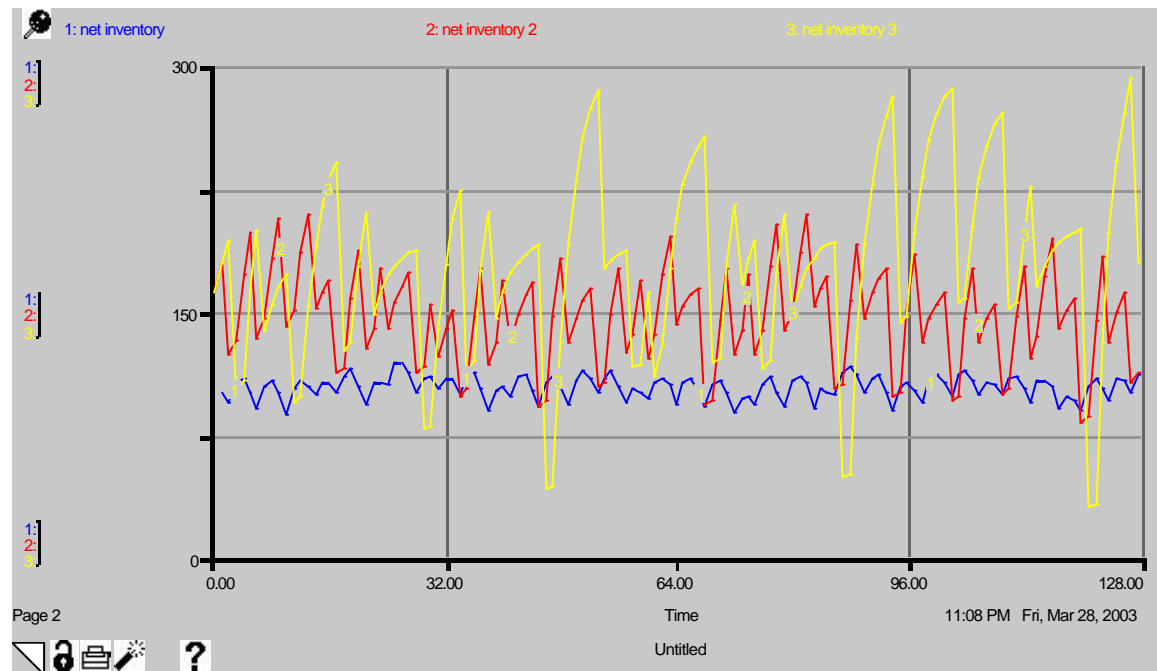The behavior of the model is given in Figure 5 " Simulation Result for (s,S) Policy".

Figure 5 " Simulation Result for (s,S) Policy"

Information Sharing Strategies

In order to explore the effect of information sharing on the behavior of the inventories, the supply chain model is modified to include end item demand sharing: Each stage uses end item demand to forecast the future demand rather than using orders of the lower stage. Hence, demand forecast obtained directly from end item demand is used in ordering decisions by all stages.

Forecast sharing means that all stages in the supply chain use the same "shared" demand forecast. Since agents in our model are identical, they all use the same forecasting mechanism with the same parameters. Thus, although demand forecasts are not explicitly shared, given that the end item demand is shared, all stages effectively use the same end item demand forecasts.

Forecast sharing means that all stages in the supply chain use the same demand forecast. Since agents in our model are identical, they all use the same forecasting mechanism with the same parameters. Given that the end item demand is shared, all stages result with same demand forecast. Thus, although demand forecast is not shared, all stages use the same end item demand forecasts.

The resulting behavior for the policies is given in Figure 6 "Simulation Result for Order-up-to S Policy with Shared Demand", Figure 7 "Simulation Result for SD Policy with Shared Demand", and Figure 8 "Simulation Result for (s,S) Policy with Shared Demand".
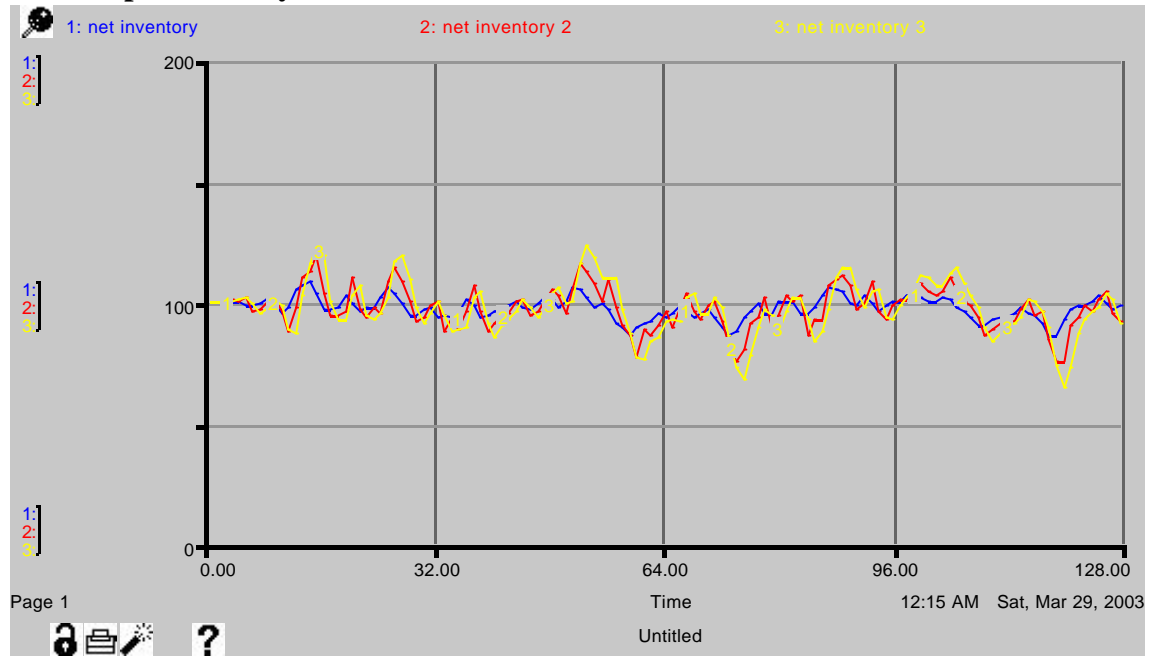
Order-up-to S Policy

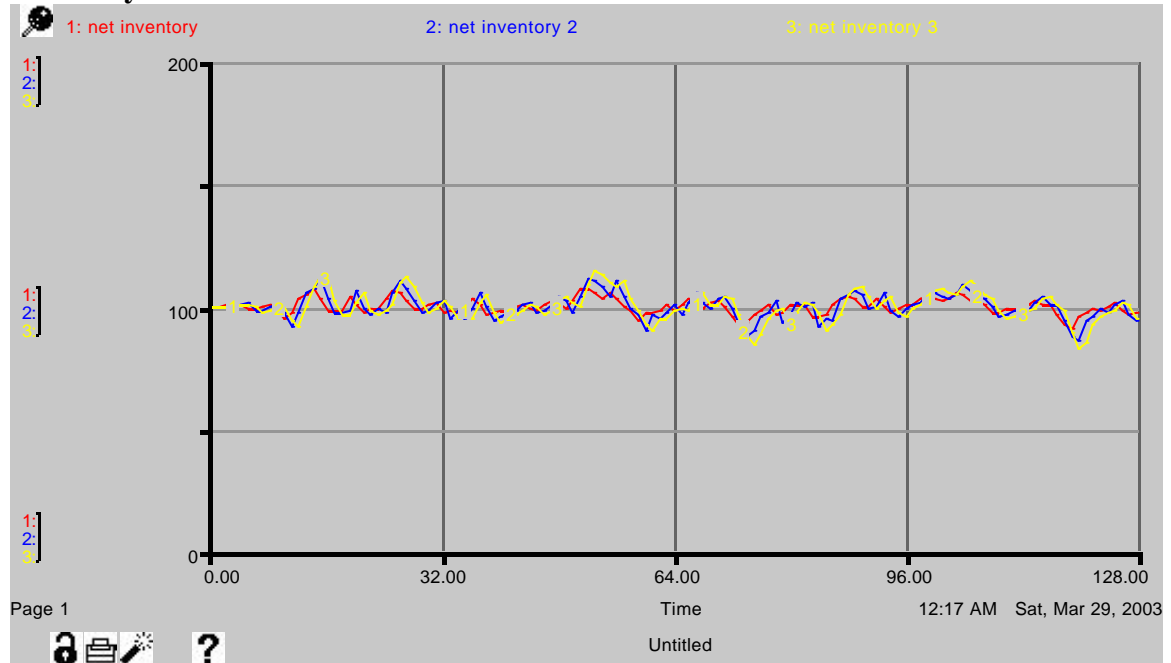**Figure 6 "Simulation Result for Order-up-to S Policy with Shared Demand"**

SD Policy

Figure 7 "Simulation Result for SD Policy with Shared Demand"
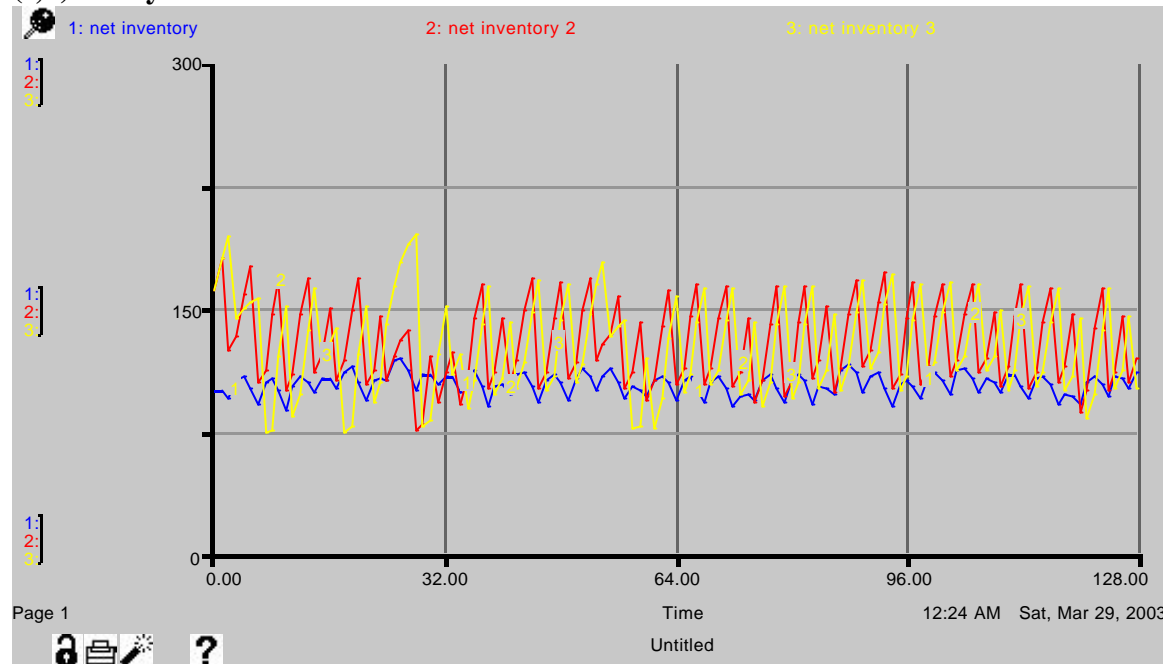
(s,S) Policy

Figure 8 "Simulation Result for (s,S) Policy with Shared De mand"

Experiments and Discussion of Results

Causes of Bullwhip Effect

Analysis of the simulation results of no-demand-sharing cases reveals that the root cause of the bullwhip effect is demand forecasting. The role of forecasted demand in ordering equation determines the bullwhip effect experienced by the chain (Gündüz 2003). S in "Order-up-to S Policy" is based only on demand forecast (S=(LT+K)*Expected Demand). As demand forecast responds to the change in the demand so does the Order-up-to level, which results in order variance to be higher than demand variance. Repetition of this characteristic along the chain is by definition bullwhip effect, which is apparent in Figure 3 "Simulation Result for Order-up-to S Policy".

For SD Policy, demand forecast appears in the desired supply line part of ordering equation, which makes orders less responsive to the changes in demand forecast. This is why bullwhip effect is not observed for this policy (Figure 4 " Simulation Result for SD Policy") (Gündüz 2003).

(s,S) Policy results show that there exists bullwhip when orders are batched. (Also see Lee et al. 1997). The reason for bullwhip is again the inclusion of demand forecast into the ordering equation.

Conditions of Bullwhip Effect

The experiments carried out with various "expectation adjustment time (EAT)"s reveal that bullwhip effect decreases with the increase in EAT. As demand forecast becomes less responsive to change in demand data, so do the orders. A very high EAT effectively means no forecast updating, yielding 'almost constant' demand forecasts.

Constant demand forecast means constant order-up-to levels, hence no bullwhip (Gündüz 2003).

Another interesting result is observed for (s,S) policy: Bullwhip effect disappears for EAT values higher than some specific value depending on other parameters of the system. This is worth mentioning since for higher values of EAT bullwhip exits but in smaller magnitude in order-up-to S policy. Reason for this behavior of (s,S) is that the batching of orders takes care of the small variations in demand.

Parametric Analysis

Experiments has been carried out with different settings of parameters EAT, LT, order-up-to level multiplier (K or q), and demand autocorrelation. Some important results are the followings:

- Bullwhip effect increases with the increase in Lead Time
- Bullwhip effect increases with the increase in Order-up-to Level (multiplier)
- Even if end item demand is totally random, upper stage inventories show cyclic pattern.

Demand Sharing and Elimination of Bullwhip Effect

Demand and forecast sharing removes independent forecasting mechanisms along the chain so that a stage no longer bases its orders on demand forecast obtained by lower stage's orders. Instead each stage directly uses end item forecast obtained by end item data. Thus consequent increase in orders is eliminated (as can be clearly seen from Figure 6,Figure 7, and Figure 8).

Another way to eliminate bullwhip is to use less responsive forecasting tools. Exponential smoothing with a high value of EAT is an example. A very high EAT effectively means no forecast updating, yielding 'almost constant' demand forecasts. When there is no forecasting, there is no bullwhip effect (Gündüz 2003).

Conclusions and Future Work

One main conclusion of this study is that one of the root causes of bullwhip effect is independent demand forecasting at every stage of the supply chain. More importantly, we show that demand and/or forecast sharing on supply chain reduce the bullwhip effect.

Note that we implemented instant demand sharing, which is very idealistic. In real world, although information technology infrastructure is highly developed, instant access to end item demand may be impossible for all the agents in the supply chain. Therefore non-ideal cases of demand and forecast sharing (e.g. time delay in shared information propagation) must also be modeled and inspected.

A corollary result is that using less-responsive forecasting tools or not to use forecasting can eliminate bullwhip effect. However, without forecasting, a manager would risk ignoring a trend in demand or some other demand pattern. Results of this could incur more cost to the overall supply chain system as compared to the cost of bullwhip effect. Therefore the non-responsive forecasting option must be analyzed carefully with different patterns of end item demand.

References

Chen, F., Z. Drezner, J.K. Ryan, and D. Simchi-Levi. 1998. The Bullwhip Effect: Managerial Insights on the Impact of Forecasting and Information on Variability in a Supply Chain. Appears in the book *Quantitative Models for Supply Chain Management*. Boston: Kluwer Academic Publishers.

Gündüz, A.B., 2003. Information Sharing to Reduce Fluctuations in Supply Chains: A Dynamic Modeling Approach. *MS Thesis, Department of Industrial Engineering, Bogazici University*

Lee, H.L., P. Padmanabhan, and S. Whang. 1997. Information Distortion in a Supply Chain: The Bullwhip Effect. *Management Science* 43:546-58.

Silver, E.A., D.F. Pyke, R. Peterson. 1998. *Inventory Management and Production Planning and Scheduling 3rd Ed*. New York: John Wiley & Sons.

Sterman, J.D. 2000. *Business Dynamics.* Boston: McGraw-Hill.

Xu, K., Y. Dong, P.T. Evers. 2001. Towards better coordination of the Supply Chain. *Transportation Research Part E* 37:35-54

Zipkin, P.H. 2000. *Foundations of Inventory Management*. Irwin/McGraw-Hill.