Strategies for Reducing Inventory Costs and Mitigating the Bullwhip Effect in Supply Chains:
A Simulation Study

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ABSTRACT

Robust, multi-echelon dynamical models are proposed for better understanding of the bullwhip effect in supply chains and for testing of strategies that mitigate it. Enterprise-wide visibility through IT and Extranet data access between trading partners and is one such strategy. Other strategies include ordering policies that do not entail the immediate replacement of used safety stocks, expanded workweek to absorb the surges in production demand. Still other strategies are possible, such as adding additional supply lines for upstream supplies. The models presented build upon existing state-of-the-art models in system dynamics as presented in existing system dynamics literature.

1.0 INTRODUCTION

Supply Chains are complex physical systems that behave badly when typical managerial practices are applied to them. For example, quantity discounts, promotional pricing, and media blitzes are examples of marketing ploys that raise havoc with the supply chain. Supply chains are the entire enterprise of suppliers and their linkages that are necessary to extract the raw materials and add value to those materials as they proceed to the point of becoming a final product, ready to be shipped to the customer.

One major concern within supply chains is the bullwhip effect. There are many different scenarios where the bullwhip effect manifests itself. In a simple case of a manufacturer catering to customer orders directly, any changes in a steady pattern of customer orders will create instability in the manufacturer's production schedules. Such changes first cause disproportionately larger changes in the work-in–process, finished good inventory levels, and lead to a bullwhip effect, which is a much higher level of changes, in the desired inventory and required production levels of the upstream suppliers.

Supply chain dynamics has been a subject of intense interest for system dynamicists. Starting with the founder of System Dynamics, Dr. Jay W.Forrester (1958; 1961), much work has been done on supply chain dynamics using system dynamics methodology. Sterman (2000), Akkermans and Dellaert (2005), and Croson and Donohue (2003; 2005) have entered recent contributions into the foray. As is well known in system dynamics literature, the typical bullwhip oscillations are caused by the presence of a 'negative feedback loop' and 'delays' present in the system concurrently (Sterman, 2000; Ch 17 pp 663 and pp 673).

Removal of information delays: Delays are two types--information delays and flow delays. Thanks to the POS scanners, integrated MRP and ERP systems, and intranet and extranet technologies, information delays have been removed to a large extent as far as communication is concerned. However, the perception and computational delays implicit in sales forecasts/tools used for these forecasts remain. Since some of these implicit information delays are too intricately imbedded in the business systems, it may be a while before we will be able to successfully separate them and address them.

Removal of flow delays: Flow delays occur for a multitude of reasons: from the physical times required for the movement of material to the essential process times involved in the manufacturing and distribution processes. From resource allocation to the scheduling and logistic issues, all of these factors contribute to the flow delays.

Obviously, if it were possible to step up the production levels to meet the required replenishment levels instantaneously without any delay, there will be no oscillations in the stock levels nor will there be any bullwhip effect. However, such is not the case in a typical business setup. Delays cannot be eliminated in that the resources, in terms of labor and production capacities, require time for adjusting to the desired levels from the current levels. Instantaneous replenishment of depleting inventory is not possible, except in the case of small retailers dealing in mass produced daily consumption items, where upstream suppliers maintain large volumes of finished goods inventory.

The remainder of this paper is organized as follows. Section 2 discusses the modeling tool and explains the general outline of the hypothetical supply chain being modeled. Additionally, section 2 also demonstrates the bullwhip effect, and the resulting disproportionate increase in operations and expenses. The results from the simulation of the base case and five alternative scenarios are presented in section 3, followed by the discussion of inferences that may be drawn from these results. Finally, section 4 lists the contributions of the current model.

2.0 MODEL DESCRIPTION

System dynamics is a modeling methodology that characterizes processes, systems as flows of goods, materials, cash, resources that are controlled by information transfers (Sterman, 2000). In this paper, we shall utilize system dynamics to capture supply chain dynamics within a two-player supply chain, where both supply chain partners are engaged in labor-intensive manufacturing processes, of a final product for supply to customers. The simulation model is developed using Vensim simulation application software (Ventana, 2005).

Brief over view of the supply chain set up. The supply chain set up assumed for this study is fairly simple and straightforward. Customers place orders for finished products with the manufacturer who manufactures the finished products using certain other manufactured inputs. Therefore, manufacturer places orders with his 'upstream partner' (hereinafter referred to as supplier) for the required inputs giving rise to production activity in the supplier's facility. Both the supplier and manufacturer carry 'work-in-process' (WIP) inventories denoting significant manufacturing cycle times. Similarly, the supplier and manufacturer have finished goods inventories and their relative policies in place. The detailed description of the manufacturer's production and inventory setup is given below, followed by a description of the underlying workforce set up of the manufacturer.

Model Structure. Exhibited below in Figure 1, is the system dynamics structure for the manufacturer's production and finished goods setup. The fundamental logic and constructs for the model structure are drawn from the state of the art models presented in Sterman (2000, chapters 17, 18 and 19). Models presented in the above-referred material deal with single player setting. We have now extended the same to a two-player (Supplier-Manufacture) setting, making suitable changes. Some portions of original models that are not under current study have been left out, and similarly new structure has been added to capture the effect of interaction between supply chain partner, as well as certain significant operational costs of both player, like the inventory costs, wage bill for the workforce, hiring costs, and lay off costs. Model structure for the supplier is substantially similar with differences in parameter settings. Only manufacturer's part of the model is being described here.

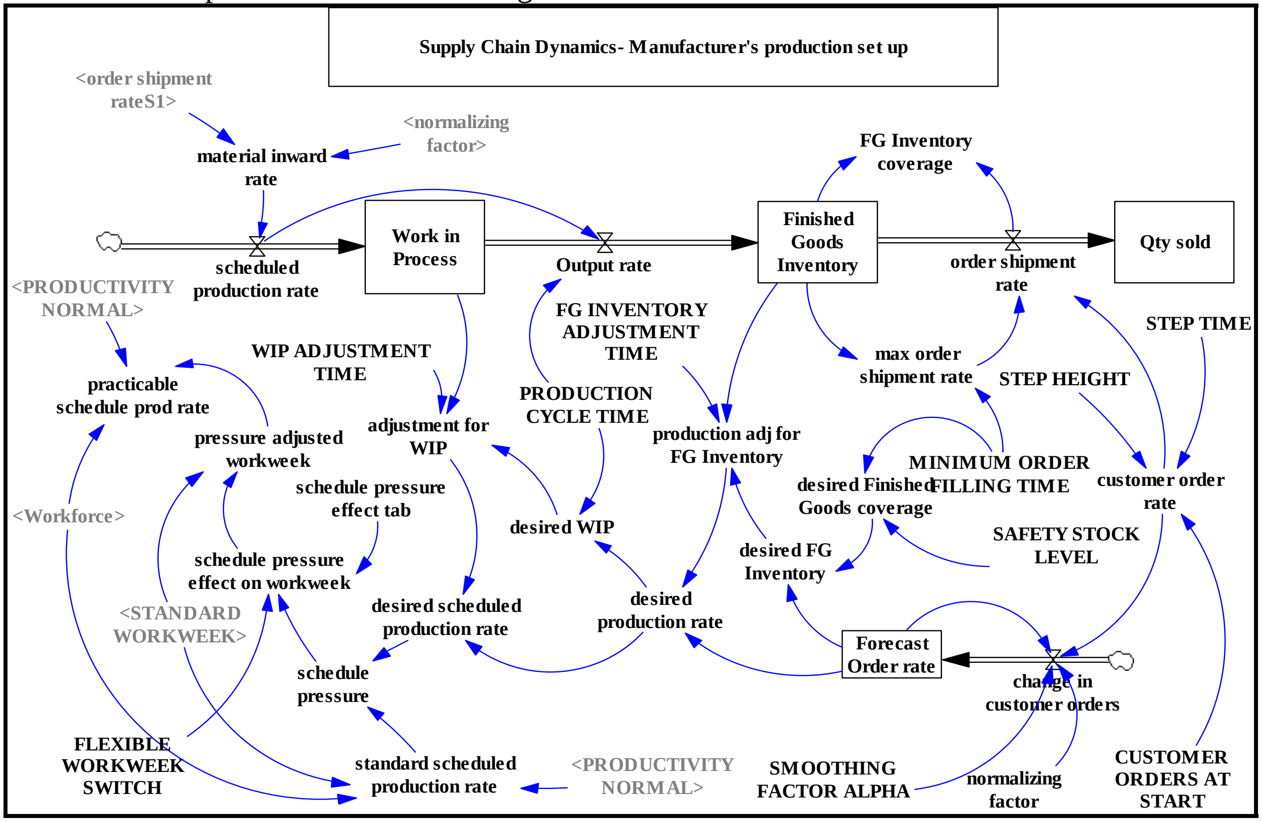

Figure 1: Production and Finished Goods Inventory view of Manufacturer

Customer orders initiate the action. Forecast order rates are revised using exponential smoothing method. Desired Finished Goods inventory (based on forecast order rates and the desired finished good coverage rate) is computed. Required adjustment for the finished stock inventory level is then computed (seeking to correct the gap in desired versus actual Inventory over the adjustment time. Then, such Finished Goods adjustment combined with the forecast order rate yields the desired production rate.

'Desired production rate' multiplied by the 'production cycle time' gives the desired WIP. Similar to the adjustment for Finished Goods, an adjustment for the WIP is computed based on the formula, (Desired WIP-actual WIP)/ WIP adjustment time. The sum of desired production rate and the adjustment for WIP yields, the desired schedule production rate.

However, the manufacturer's production plans are limited by two main factors, availability of inputs in required numbers, and availability of required workforce. Based on available 'workforce,' 'standard workweek,' and 'productivity normal' standard production schedule rate is compared. Based on desired and standard scheduled production rates, a 'schedule pressure' index is computed. Schedule pressure>1 indicates shortage of workforce, and schedule pressure < 1 indicates excess of workforce. Based on this index, management may adopt a Flexible workweek that may extend beyond standard workweek of 40 hours, or shrink below 40 hours. Based on such adjusted workweek, practicable scheduled production rate is computed. Such 'practicable production schedule rate' is communicated as the order to the supplier for inputs for the next time-period. However, the actual scheduled production rate of the manufacturer is limited to the physical receipts of inputs from suppliers that are based on the orders placed at a prior point of time. The following structure of the workforce in Figure 2, explains how the desired scheduled production rate affects the workforce adjustments.

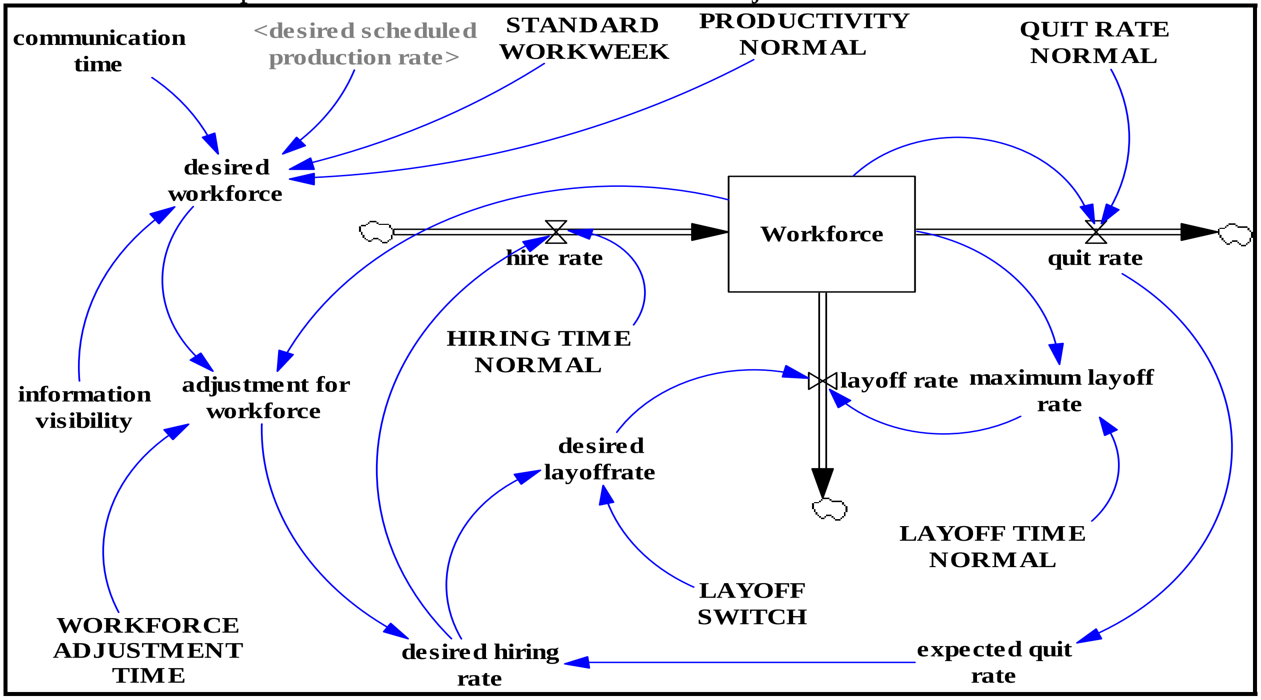

Figure 2: Workforce view of the Manufacturer

Desired scheduled production rate, standard workweek, and productivity normal yield the 'desired workforce' to support the production operations. Typically, in the absence of information visibility between functional areas, there is one time period delay of communicating the desired schedule production rate to the personnel department. Based on management's policy of adjusting the gaps in workforce, desired versus actual, an adjustment for workforce is computed. Manufacturer's workforce is regularly depleted by the quit rate (also same as expected quit rate for next period) of the workforce. Desired hiring rate is the sum of expected quit rate and adjustment for workforce, to maintain equilibrium level of workforce. However, only positive values of desired hiring rate result in recruitment of workforce. If desired hiring rate is negative (-) then such rate is used in computing the 'desired lay off rate' depending upon management's policy on lay off (lay off switch value 1=yes and 0 = no) workforce is laid off.

Figure 3 given below shows the capture of significant operational costs in the model, to compare the effect of alternate strategies in terms of costs of interest to the management.

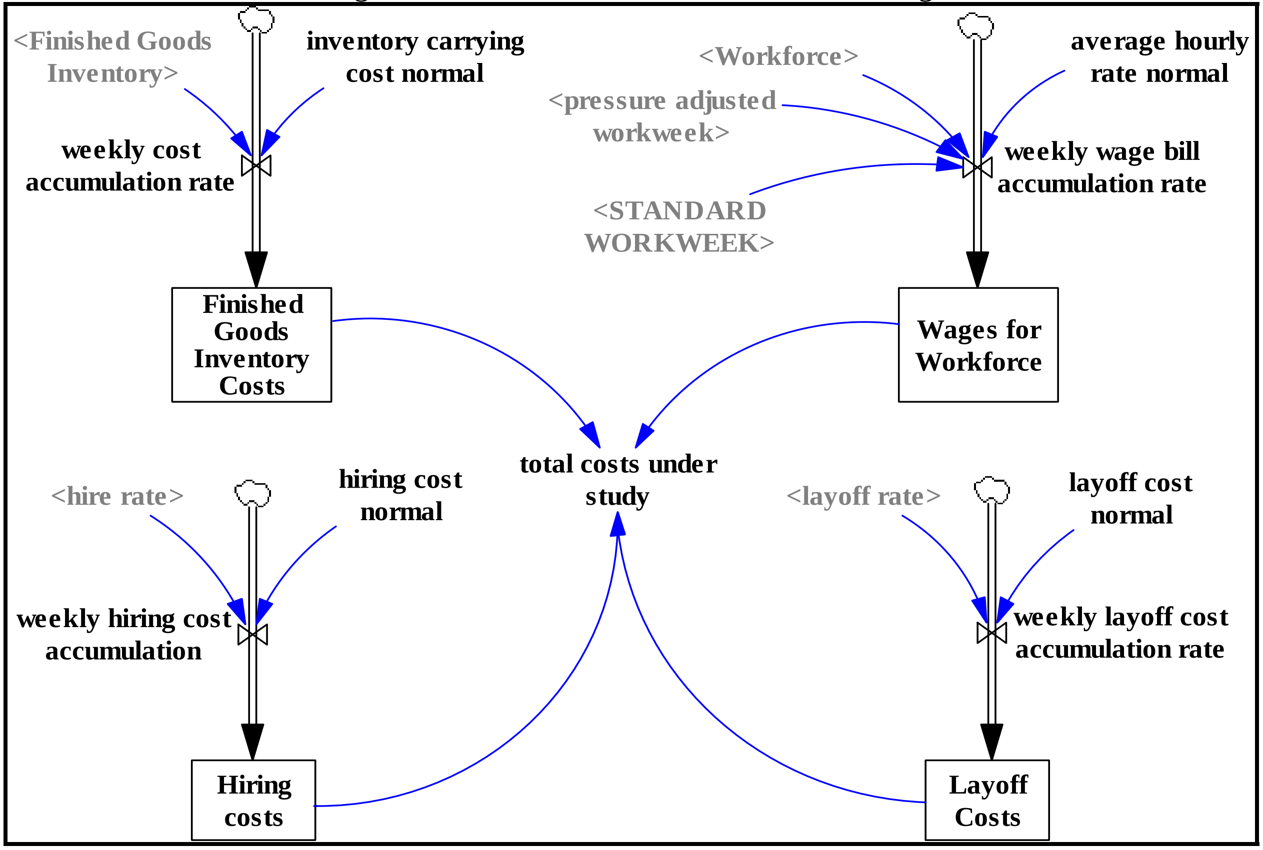

Figure 3: Significant Inventory and Labor costs of manufacturer

Weekly (week is the unit of time in this model) inventory costs are accumulated based on the Finished Goods inventory level, and the applicable carrying cost normal. Similarly, weekly wage bill is accumulated taking care to record overtime wages when workweek extends beyond 40 hours. However, no cognizance of workweek shrinkage to below 40 hours, is taken for wage computations because of statutory obligations or otherwise. Hiring costs accumulation is simple enough and so is the lay off cost accumulation which is computed only under scenarios where relative lay off switch is set 'on' in the models.

Initial Parameter /Policy Setting for Manufacturer and Supplier. Although, the model structure is similar for the manufacturer and the supplier, certain differences in their policy parameters are assumed in the model due to the different roles they play in the supply chain. For example, while the manufacturer uses a smoothing alpha of 0.125 for forecasting customer orders (denoting higher reliance on current forecasts than current period actual orders), supplier is assumed to use a smoothing alpha S1 of 0.50, denoting equal weighting of current period forecast and the orders received from manufacturer. Table 1 given below lists the initial values for the major stocks and policy parameters of the manufacturer and the supplier in the model.

Parameter	**Unit**	**M**	**S**
Production and Inventory			
Simulation Time	weeks	500	500
Customer Orders at start	units/week	10000	n.a.
Orders from manufacturer	units/week	n.a.	10000
Step Time	weeks	6	n.a.
Step Height	dimensionless	0.2	n.a.
Smoothing Alpha	dimensionless	0.125	0.5
Min Order Filling Time	weeks	1	1
Safety Stock level	weeks	2	1
FG Inv Adj Time	weeks	15	10
Production Cycle Time	weeks	8	6
WIP Adj Time	weeks	4	4
Standard Workweek	hours	40	40
Flexible workweek -max	hours	50	50
Flexible workweek -min	hours	30	30
Productivity Normal	units/(hour*person)	0.25	0.5
WIP	units	80000	60000
Finished Goods	units	30000	20000
Workforce View			
Workforce Adj Time	weeks	8	8
Communication time	weeks	1	1
Hiring Time Normal	weeks	1	1
Layoff Time Normal	weeks	8	8
Quit Rate Normal	dmnl/week	0.01	0.01
Workforce	person	1000	500
Inventory/Labor Costs View			
Inventory Cost Normal	dollars/(unit*week)	0.1	0.1
Hourly Rate Normal	dollars/(person*hour)	12	12
Overtime wages	times normal wage	1.5	1.5
Hiring Costs Normal	dollars/person	100	100
Layoff Costs Normal	dollars/person	250	250

Table 1: Initial and Parameter Settings (M=manufacturer; S=supplier)

As may be seen from the simple results showing in following Figures 4 and 5, a small increase of 20% in the customer orders starting the sixth week produces disproportionately higher increase in Finished Goods (and WIP) inventory requirements. However, after adopting policy 2 of flexible workweek, good part of the oscillations and thereby the bullwhip effect is reduced as will be seen in figure 6. Subsequent policies 3, 4, and 5 are aimed at reducing the minimal surge seen in the figure 6. While policy 4 and 5 provide acceptable results, policy 3 appears to produce a much higher-level instability and bullwhip, and as such is unadvisable.

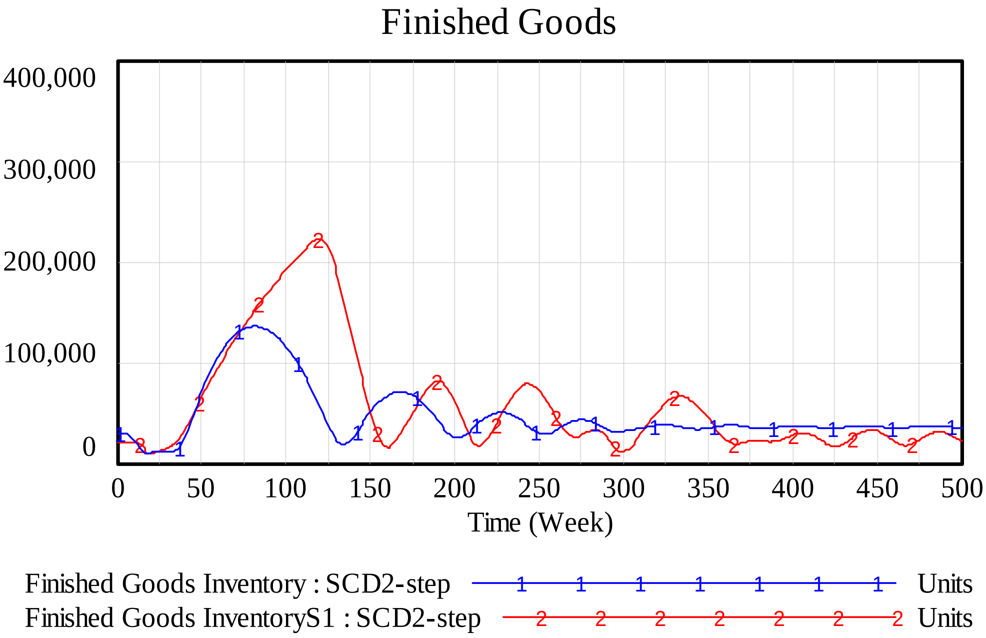

Figure 4: Finished Goods Inventory for Manufacture and Supplier
With a nominal 20% increase in customer orders

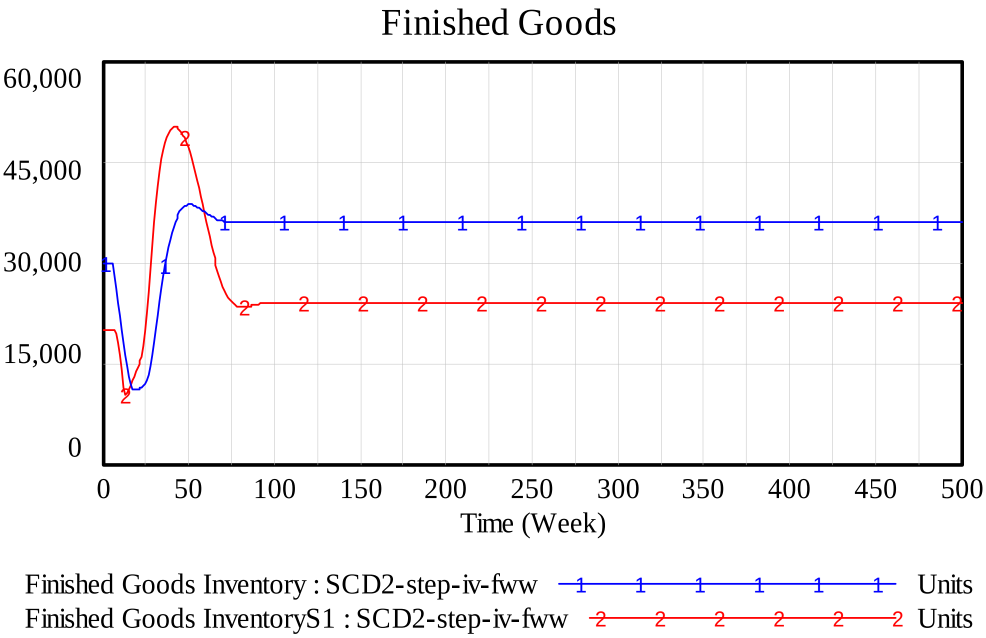

Figure 5: Finished Goods Inventory for Manufacture and Supplier,
upon adopting Flexible workweek

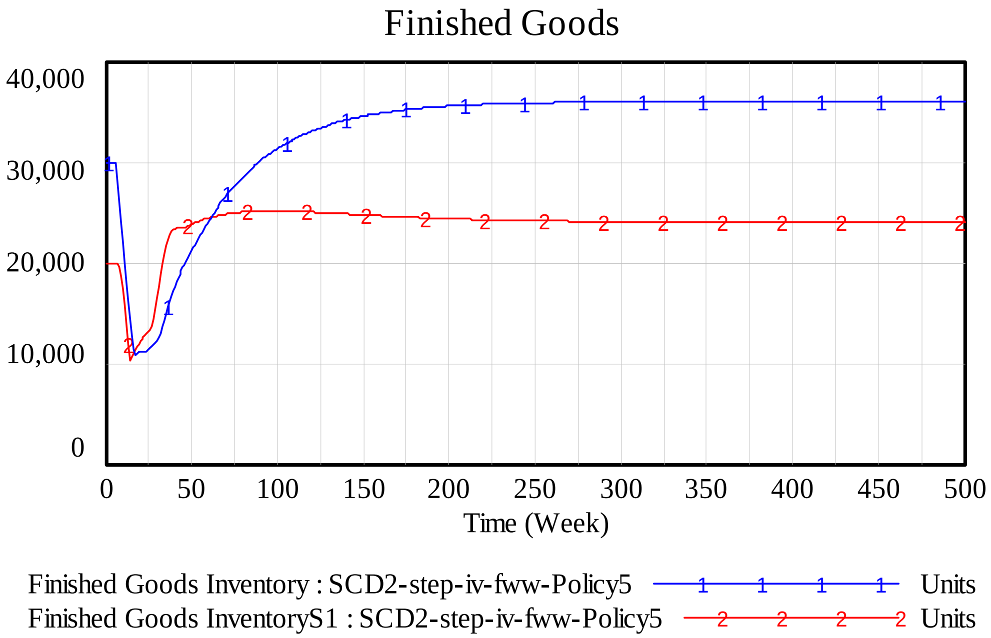

Figure 6: Finished Goods Inventory for Manufacturer and Supplier, under Policy 5 (Finished Goods adjustment time= 50 weeks)

3.0 RESULTS FROM ALTERNATE POLICIES

Summarized results from the various policies are presented in Table 2. For obvious reasons, the basecase results are best in terms of lower costs, since the system in steady, equilibrium state. However, a 20% increase in customer orders produces greater than 20% increase in the costs; Compare $242M of SCD2-basecase with $ 293.29Mof SCD2-step results.

Information visibility (removal of communication delays) improves the results further by taking the total costs for manufacture down to $292.75M under the SCD2-step-iv. Nearly half a million savings over 50 weeks or say $50,000/year approximately.

Adoption of flexible workweek by either manufacture or supplier alone doesn’t appear to help significantly in terms of cost reduction, although a certain level of stability is obtained in respect of schedules of production of the adopting party. However, when both partners of supply chain adopt the flexible workweek, delays in adjustment of labor do not have much impact on the schedules and thereby the bullwhip effect is minimized (refer to Figure 5 above) and the financial results for both partners improves significantly under the option SDC2-step-iv-fww.

Adoption of flexible workweek is essentially removing the delay in acquiring the required workforce levels, to accomplish higher-level production rates. *Therefore, there is an indirect removal of flow delay (of additional workforce flowing into the system)* It is well known fact that laying off of workforce has significant adverse effects on productivity, labor morale and other such factors. However, lay off options must be used as an exception rather than a practice. This assertion is supported by the results obtained under policy 3 of adopting the lay off switch.

Two player setting						**5,990,000**
Parameters	**step height**	**Inf Visibility**	**FWW**	**Layoff switch**	**total costs**	**qty sold**
SCD2-basecase – M	0	0	0	0	$ 242,000,000	5,000,000
SCD2-basecase – S	0	0	0	0	$ 121,250,000	5,000,000
SCD2-step – M	0.2	0	0	0	$ 293,285,901	5,965,000
SCD2-step – S	na	0	0	0	$ 147,257,974	5,989,000
Policy 1- communication gaps removed						
SCD2-step-iv – M	0.2	1	0	0	$ 292,748,439	5,972,000
SCD2-step-iv – S	na	1	0	0	$ 146,841,650	5,996,000
Policy 2-Flexible Workweek						
SCD2-step-iv-fww-a – M	0.2	1	1	0	$ 293,263,653	5,977,000
SCD2-step-iv-fww-a – S	na	1	0	0	$ 147,134,899	6,001,000
SCD2-step-iv-fww-b – M	0.2	1	0	0	$ 291,951,030	5,977,000
SCD2-step-iv-fww-b – S	na	1	1	0	$ 146,542,286	6,001,000
SCD2-step-iv-fww – M	0.2	1	1	0	$ 292,285,312	5,982,000
SCD2-step-iv-fww – S	na	1	1	0	$ 146,407,139	6,006,000
Policy 3-use Layoff						
SCD2-step-iv-fww-Loff – M	0.2	1	1	1	$ 292,294,348	5,982,000
SCD2-step-iv-fww-Loff – S	na	1	1	1	$ 146,514,718	6,006,000
Policy4-do not bother to build up Finished stock inventory						
all setting of SCD2-step-iv-fww						
SCD2-step-iv-fww-Policy4 – M	0.2	1	1	0	$ 288,722,479	5,974,000
SCD2-step-iv-fww-Policy4 – S	na	1	1	0	$ 144,770,105	5,974,000
Policy5-build up the Finished stock inventory over 50 weeks (FG inv adj time=50)						
SCD2-step-iv-fww-Policy5 – M	0.2	1	1	0	$ 291,373,925	5,978,000
SCD2-step-iv-fww-Policy5 – S	na	1	1	0	$ 146,093,545	6,002,000

Table 2: Simulation run results of alternate policies

Policy 4 and Policy 5 are adopted on top of Flexible workweek, but turning lay switch to 'no' position. Policy 4 is the adoption of a policy of ignoring to build up finished stock. This policy may be dubbed as going 'lean' based on the confidence one has in the reliability of Supply Chain set up, and the uninterrupted operation of production facility (only if there are no other compelling reasons for maintaining safety stocks). Obviously, the results are better than those under policy 2 are. However, if there are compelling reasons for maintaining safety stocks then policy 5 of adopting a slower rate of accumulation of finished stocks will help achieve good results. Its is interesting to note that under policy 5 by changing the Finished Goods Adjustment Time to 50 weeks (and for that matter under policy 4 as well by totally ignoring it), *the negative feedback effect of, 'dwindling finished stock on the need for increase in production requirements,' is minimized.*

4.0 CONCLUSION

Suppose the manufacturer is able to provide the supplier access to the entire sequence of estimations starting from, actual customer orders through desired finished stock, desired work-in-process. There is still no guarantee that the supplier will be able to use such information to his advantage because of 'perception delays.' The supplier may not be able to appreciate the significance of the rising volume of orders and may blindly accept the manufacturer's weekly orders as accurate and schedule his production accordingly and thereby experience the bullwhip effect. So understanding the cause of the oscillations and the bullwhip effect is the first step in mitigating the bullwhip effect. Once the attending factors are appreciated in the right perspective managements will be able to achieve best results by suitably adopting the required strategy.

The elimination of delays in the information infrastructure has been seen to significantly reduce the cost of holding inventory and other operational costs as well. This, in turn, results in improvements in quality and reductions in cycle time. To achieve the benefits suggested here in terms of reduced inventory, two things must happen. First, enterprise-wide visibility must be possible through the supply-chain information infrastructure. Second, the old inventory ordering policy is a "sacred cow that must be slaughtered" to allow a new policy to be put in place that takes advantage of the new information infrastructure.

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