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Inventory Policies for Supply Chains

A System Dynamics Model based Study

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***Abstract* - A two player, Manufacturer - Retailer, System Dynamics (SD) model is used to understand the effect of various changes in inventory policies in meeting different objectives in supply chains. Depending upon the definition of the objective function policies could be specifically formulated to achieve them. While information visibility is a desirable feature to reduce the safety stock levels both at supplier and retailer facilities, maintenance of certain levels of safety stocks could definitely come in handy when there are unexpected disruptions in the production process or the transportation between supply chain partners.**

***Keywords:* Inventory policies, Supply Chain Dynamics, System Dynamics, Optimization, Simulation modeling**

I. INTRODUCTION

Supply Chains are complex business systems. Many seemingly simple and successful management policies fail to yield the expected results when applied in supply chain settings. Typically, business executives blame these failures on unforeseen side effects of the decisions or changes in the business scenarios. Investors and supply chain partners alike, accept this explanation as a feature of reality. However, the true reason for this phenomena of so called side effects in the words of Sterman [1] is, "Side effects are not a feature of reality but a sign that our understanding of the system is narrow and flawed." There is no denying that there is an urgent need for improving our understanding of complex supply chain systems.

This study is part of a series of studies aimed at gaining a deeper and better understanding of supply chain dynamics using System Dynamics modeling methodology. In previous studies [2, 3, 4], effects of reductions in information delays and flow delays as well as forecasting/smoothing upon supply chains have been explored. The focus of the current study is a two player manufacturer (supplier) and retailer supply chain. The objective is to ascertain desirable inventory policies for adoption by the retailer and supplier manufacturer aimed at different objective functions under different scenarios.

Beamon [5] has identified four main categories of models used in analyzing and designing supply chains as follows,

> "(1) deterministic analytical models, in which the variables are known and specified, (2) stochastic analytical models, where at least one of the variables is unknown, and is assumed to follow a particular probability distribution, (3) economic models, and (4) simulation models" [5].

Supply chain dynamics has been fairly well researched by system dynamicists. Beginning with the founder of System Dynamics, Dr. Jay W. Forrester [6, 7] considerable research on supply chains has been contributed by Sterman [1], Akkermans and Dellaert [8], and Croson and Donohue [9, 10]. System Dynamics is a continuous deterministic simulation modeling suitable for studying complex business systems. "Dynamic complexity" and "feedback loops" present in them, lend supply chains to a study in System dynamics [1]. From a system Dynamics perspective, "Supply chains consist of stock and flow structure for the acquisition, storage, and conversion of inputs into output and the decision rules governing the flows," Sterman in Business Dynamics [1].

Two types of delays are modeled and discussed in System Dynamics modeling. –information delays and flow delays. As a matter of fact, both types of delays are quite intricately interlinked. With the developments in Information and communication technologies (ICT) information delays have been reduced considerably in supply chains. However, the perception and computational delays implicit in demand forecasts/tools used for these forecasts persist.

Suppose that a retailer is able to provide his supplier access to the entire sequence of estimations starting from, actual customer orders through desired finished stock. 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 retailer's weekly orders as accurate, schedule his production accordingly and thereby experience de-stability in operations.

On the other hand, flow delays occur for various reasons, including the communication, perception, and computational delays. One of the main reasons for the flow delays is time required for physical movement of material, as well as the time required for transformation of inputs into desired output (technically known as production cycle time). Further, resource allocation, scheduling, and logistic issues, all contribute to the flow delays. For obvious reasons, flow delays can't be eliminated altogether. E.g. resources in terms of labor and production capacities require time for adjusting to the desired levels from the current levels. So

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also, instantaneous replenishment of depleting inventory is not possible, except in the case of small retailers dealing in mass produced daily consumption items.

The remainder of this paper is organized as follows. Section 2 discusses the modeling tool and explains the general outline of a hypothetical manufacturer supplier–retailer supply chain set up. The results from the simulation of the basecase and several sets of alternative scenarios are presented in section 3, followed by the discussion of insights that may be gained from these results. Finally, section 4 lists the contributions/limitations of the current study and directions for future studies.

II. MODEL DESCRIPTION

In the words of Sterman [1], System Dynamics is a modeling methodology that characterizes processes, systems as flows of goods, materials, cash, resources that are controlled by information transfers. As stated earlier, in this study, we employ System Dynamics modeling to capture the production system of a manufacturer engaged in moderately labor-intensive manufacturing of a final product for supply to his retailer, who in turn supplies it to end-users. The simulation model is developed using Vensim application software [11].

A. Brief over view of the supply chain set up

The supply chain set up assumed for this study is quite simple and straightforward Customers place orders for products with the retailer who places orders with his 'upstream partner' a manufacture (hereinafter referred to as supplier) for the required products. Both the retailer and supplier carry Finished Goods inventories and relative policies. However, the supplier who is also the manufacture, carries 'work-in-process' (WIP) inventories denoting the presence of manufacturing cycle times. Similarly, the supplier and retailer have order forecasting policies in place using "exponential smoothing" method with a smoothing alpha of 0.5 denoting a conservative approach

B. Model Structure

Figure 1, shows the System Dynamics structure for the retailers finished goods and customer order forecasting setup. The basic constructs for the model structure are drawn from the state of the art models presented in Sterman [1, chapters 17, 18 and 19]. The model structure for the supplier manufacture is similar with differences that it includes the production set up as well and thereby it contains the work in process and input coming from upstream supplier. Additionally, manufacture supplier also has a workforce set up including hiring rate, quit rate, production normal, and overtime production when required etc. Accordingly, retailer's set up is described first, followed by the additional structures found for supplier manufacturer's set up.

C. Retailer's set up

A week is the unit of time in this model. Customer orders initiate the action. The retailer has a choice of forecasting methods to choose from, starting with a naïve forecast, a 3 period moving average, through simple exponential smoothing with alternate rates for a "smoothing alpha" (exponential smoothing with alpha=0.50 used in simulations). Forecast order rates are revised accordingly. Desired Finished Goods inventory (based on forecast order rates and the desired finished good coverage rate; safety stock is 1 week to start with) 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 (which is the lead time and is 1 week in this case). Then, such finished goods adjustment combined with the forecast order rate yields the desired order rate which is communicated to the supplier manufacture.

D. Supplier-manufacturer's setup

Figure 2 below depicts the supplier manufacture's setup.

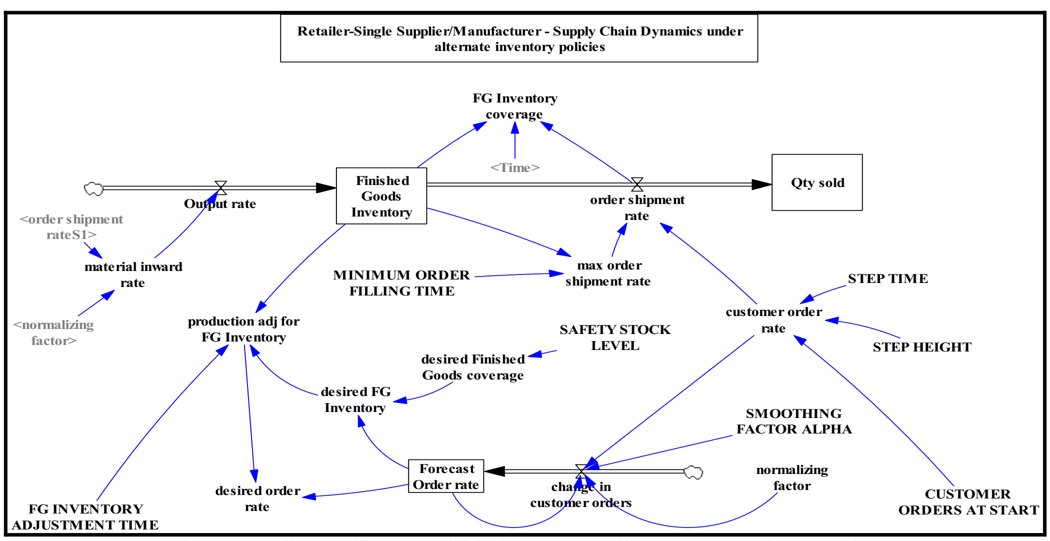

Figure 1: Retailer's facility setup- finished goods, order filling, customer order forecasting

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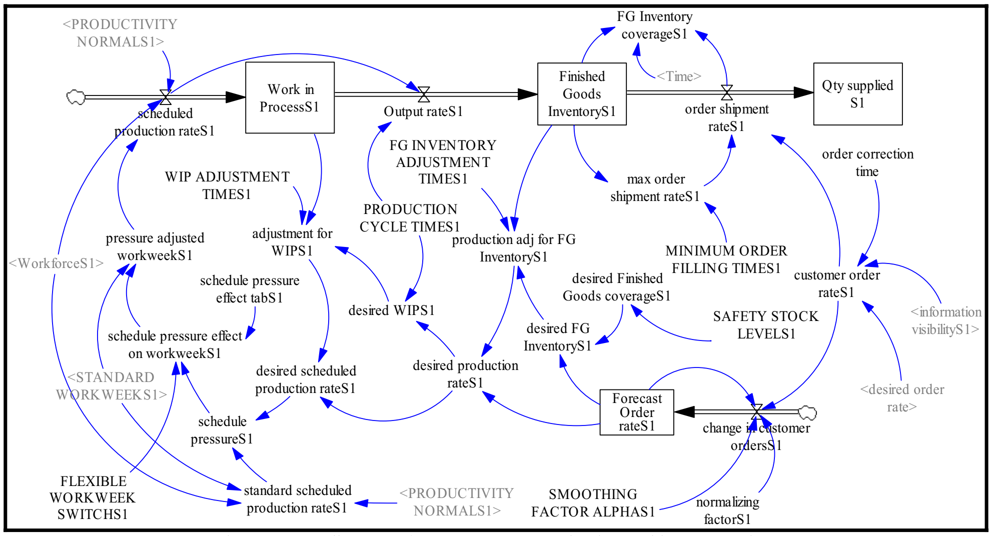

Figure 2: Supplier manufacturer's setup- production and inventory view

When retailer communicates his order, the supplier manufacturer has a choice of forecasting methods to choose from. In this case we are assuming that he is using an exponential smoothing with alpha=0.50. Forecast order rates are revised accordingly. Desired Finished Goods inventory (based on forecast order rates and the desired finished good coverage rate; safety stock is 1 week again) 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 (which is the production cycle time and is 4 weeks in this case). 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.

Here, desired production scheduled rate is compared with standard production scheduled rate (based on available workforce and productivity normal) to compute a "Schedule pressure" which determines, when "flexible work week switch is turned on," if a departure from the normal work week of 40 hours is desirable. If the pressure is higher the workweek is extended to anywhere up to a maximum of 50 hours and likewise, when the schedule pressure slacks off, work week is compressed anywhere down to 30 hours. When flexible work week switch is turned off, work week remains steady at 40 hours.

Table 1: Initial parameter settings

Parameter	**Unit**	**Retailer**	**Supplier**
Production and Inventory			
Simulation Time	weeks	300	300
Customer Orders at start	units/week	10000	N/A
Orders from retailer	units/week	N/A	10000
Smoothing Alpha	dimensionless	0.5	0.5
Min Order Filling Time	weeks	1	1
Safety Stock level	weeks	1	1
FG Inv Adj Time	weeks	1	4
Production Cycle Time	weeks		4
WIP Adj Time	weeks		4
Standard Workweek	hours	40	40
Flexible workweek –max	hours	50	50
Flexible workweek –min	hours	30	30
Productivity Normal	units/(hour*person)		0.5
WIP	units		40000
Finished Goods	units	10000	10000
Workforce View			
Workforce Adj Time	weeks		6
Communication time	weeks	1	1
Hiring Time Normal	weeks	N/A	1
Quit Rate Normal	dmnl/week	N/A	0.01
Workforce	person	Not relevant	500

The following structure of the workforce in Figure 3 explains how the desired scheduled production rate influences the workforce adjustments. 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. However, except in respect of basecase scenarios we assume no such delay here, since information visibility is presupposed in all subsequent scenarios. 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. The desired hiring rate is the sum of the expected quit rate and the adjustment for workforce, to maintain an 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 or is not laid off. For simplicity here, we assume no lay-offs policy.

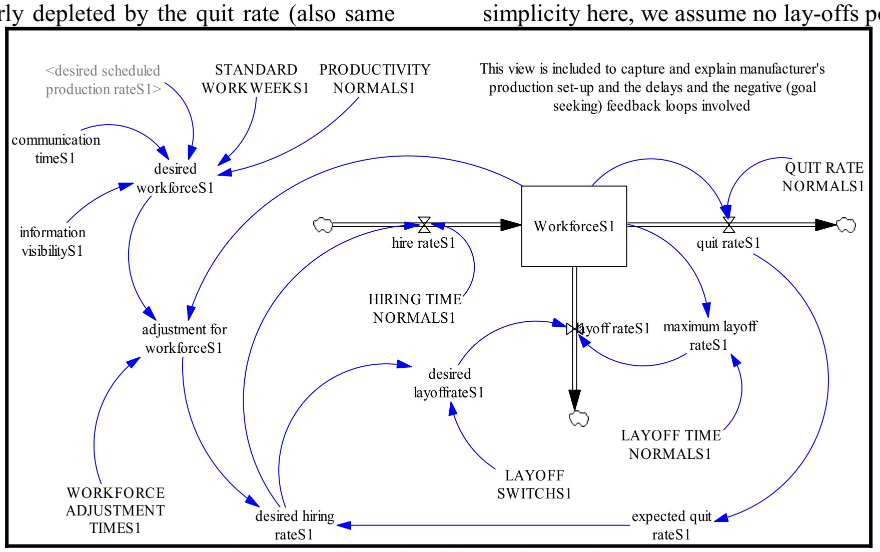

Figure 3: Workforce view of the supplier manufacturer

E. Initial Parameter /Policy setting for retailer and his supplier manufacturer

Although, the model structure is similar in respect of finished goods and forecasting aspects, there are definite differences in other aspects due to nature of their activities. However, both supply chain partners are using a simple exponential smoothing method for forecasting demand with a smoothing alpha of 0.500, denoting equal weighting of current period forecast and the orders received. Table 1 given above lists the initial values for the major stocks and policy parameters of the manufacturer and the supplier in the model. Running time for the simulation is 300 weeks. Table 2 below summarizes the various customer order scenarios simulated in this study

Additional model structure includes stocks necessary to capture /accumulate the unfilled orders at retailer's facility (customer order rate-order shipment rate) and the finished goods inventory costs at the manufacturer's facility (inventory*carry cost rate per week) respectively.

Further below, Figure 4 depicts the customer order levels under each scenario. Under the base case scenario, there is no change in the steady rate of customer orders and as such the manufacturer's schedules run like clock work. Under other scenarios the customer orders vary as above. The objective in choosing these variations in orders is to develop insights into resultant response behavior of the system under alternate scenarios.

Table 2: Customer order scenarios and the alternate forecast methods

Scenarios	**Description**
Basecase	No changes in customer orders of 10,000 units/week Information visibility turned off and flexible work week is turned off
RAMP	Customer orders first go up from week 15 to 35 at 100 units/week and then down from week 65 to 85 at 100 units/week.
RAMPIV	RAMP plus information visibility turned on.
RAMPIVFWW	RAMPIV plus Flexible work week is turned on.
RandomUniformIVFWW	From week 16 customer orders arrive at random uniform rate in the interval of 8000-12000 units/week plus information visibility and flexible workweek on
Optimization runs	**On the top of the two broad scenarios as above**
Minimize unfilled orders at retailer	Unfilled orders at retailer represent loss to supply chain- hence the primary objective is to minimize it- search for inventory levels.
Minimize unfilled orders and supplier's inventory costs	Simultaneous pursuit of two objectives- search for inventory levels
Minimize unfilled orders and supplier's inventory costs and tweak smoothing alpha	Simultaneous pursuit of two objectives- search for inventory levels as well as smoothing alpha

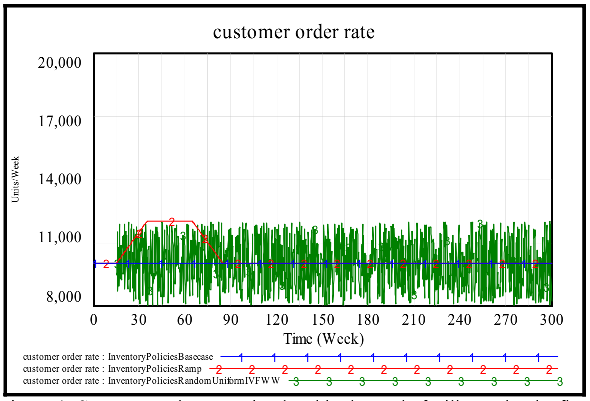

Figure 4: Customer order rates simulated in the study facility under the first four scenarios.

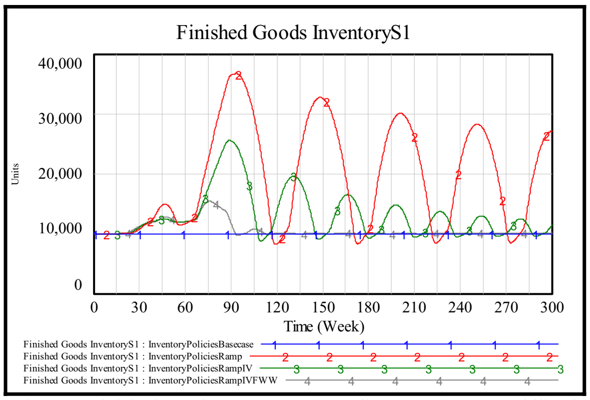

Figure 5: Finished Goods Inventory of Supplier Manufacturer stabilized with Information Visibility and Flexible Work Week policies

III. RESULTS FROM SIMULATIONS

As discussed, we start the model simulation with the basecase, where system is in steady state and the customer orders are received steadily at 10,000 units/week. Inventory policies (one week safety stock) and forecast policies (exponential smoothing with alpha=0.50) are working perfectly for the retailer as well as his manufacturer supplier. Then we continue with scenarios listed in table 2. Figure 5 captures the finished good inventory at supplier's

As may be observed, the inventory policies and forecast practices that were working very well in a steady state (curve1) are of little help when the customer orders are changed (curve 2). However, removal of information delays by providing information visibility brings in considerable stability to inventory levels (curve 3). Adding flexible workweek policy on the top of information visibility brings in much better stability to the inventory levels (curve 4). There is increased stability with information visibility and Flexible work week policies combined. Notice how curve 4(IV+FWW) converges with curve 1(base case). This result is in keeping with the findings reported in Janamanchi and Burns [3].

Similarly, Figure 6 captures the stability in manufacturer's work-in-process levels with information visibility and flexible workweek. However, unfilled order of retailer is a cause of concern as may be seen from figure 7 further below.

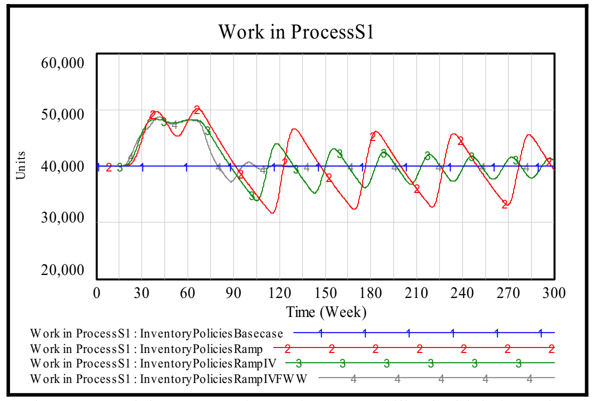

Figure 6: Work in process of manufacturer stabilized with information visibility and flexible work week policies.

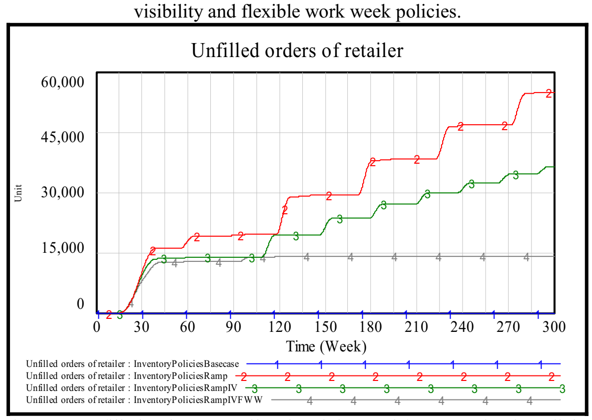

Figure 7: Unfilled orders at retailer signal the need for correction in policies

For obvious reasons, supply chain managers would like to eliminate or curtail the unfilled orders at the retailer. Accordingly, we define our objective function and attempt optimization of the model to develop useful insights into model behavior and policy parameters.

A. Objective functions and Optimization

Vensim environment provides for optimization runs and select the parametric values for optimizing with reference to an objective function. First we need to define our objective function and include it suitably in our model. Typically, optimization process seeks to maximize the value of the objective function. However, by assigning negative weights, we can attempt minimizing instead of optimizing a desired objective function. So we attempt the following options with two different objective functions.

Objective function1: The primary objective of a supply chain is to ensure that the end user receives the required products at the required time. So in other words, objective function could be defined to minimize the unfilled orders at the retailer. After all, retailer is the only one who is in direct contact with the end user and the unfilled orders at retailer signal poor customer satisfaction.

.**Objective function2:** While unfilled orders minimization is important, it is also important to keep the costs of operations low, so the inventory carrying costs is a secondary objective function. Combining the two, we can define a new objective function of simultaneous minimization of unfilled orders and inventory costs. As a matter of fact, depending upon how important either of the two, one could assign appropriate weights to define the objective function. For simplicity's sake, we assume equal weight for both parts of the objective function.

Optimization Scenario 1(objective function 1): Find optimal parametric settings for inventory levels to minimize the unfilled orders at the retailer under RAMPed up customer orders as well as RandomUniform level customer orders.

This effort yields very good result so far as achieving the objective function of minimizing the unfilled orders but leaves much to be desired in terms of inventory carrying costs given that the recommendation obtained suggests, inventory of 1.5 weeks at retailer and 2 weeks at the supplier manufacturer.

The recommendation is same for both RAMPed up customer orders as well as RandomUniform customer orders scenarios.

Optimization Scenario 2 (objective function 2): Find optimal parametric settings for inventory levels to minimize simultaneously the unfilled orders at retailer as well as the inventory carrying costs of supplier manufacturer. This objective function provides us improved result of reduced inventory levels as well.

Optimization Scenario 3 (objective function 2 under improved settings): Find optimal parametric settings for inventory levels as well as the smoothing alpha used for forecasting to minimize simultaneously the unfilled orders at retailer as well as the inventory carrying costs of supplier manufacturer.

Table 3 below summarizes the parameters obtained under all three optimization runs

Table 3: parametric settings obtained under optimization runs

.	**RAMPIVFWW**				**RandomUniformIVFWW**			
Optimization runs	Retailer FG level Weeks	Supplier FG level weeks	Retailer alpha	Supplier alpha	Retailer FG level weeks	Supplier FG level weeks	Retailer alpha	Supplie r alpha
Minimize unfilled orders at retailer	1.50	2.00	*	*	1.50	2.00	*	*
Minimize unfilled orders and supplier's inventory costs	1.418	1.023	*	*	1.19	1.00	*	*
Minimize unfilled orders and supplier's inventory costs and tweak smoothing alpha	1.00	1.00	1.00	1.00	2.00	1.03	0.003	0.000

* not searched for and allowed to remain at 0.50 as initially set.

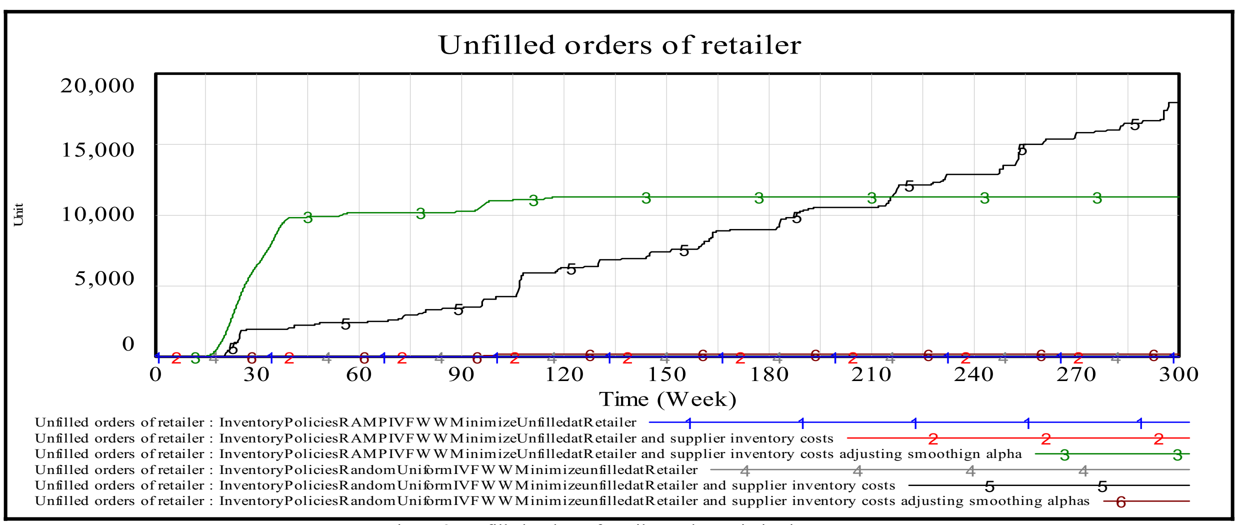

Figure 8: Unfilled orders of retailer under optimization runs

Figure 8 above depicting the unfilled orders under optimization runs provides some useful insights. As may be observed from Table 3 and Figure 8 above, when the objective function is set to minimize the unfilled orders, inventory levels are allowed to be higher to ensure accomplishing the objective. However, when inventory costs is included in the objective function, then inventory levels are curtailed, albeit, allowing unfilled orders to rise in at least one case (refer curve 5). When search for parametric settings is expanded to include the smoothing alpha, then the inventory levels are further trimmed with the help of better alphas, except for retailer's inventory level at 2.00 weeks (since that was never included in the objective function). A very important insight in respect of smoothing factor alpha is that, in case of increasing or decreasing trend of customer orders, chasing the orders closely is recommend (alpha=1). Whereas, when customer orders appear to hover around a mean (random uniform case), random variations are best ignored for better results in the objective function (alpha nearly $\cong$ 0). In both cases safety stock is relied upon to absorb the gaps, if any, between demand and supply.

The intent here is to suggest the need for an analytical assessment of alternate objective functions and the relative parametric settings to understand that defining a comprehensive objective function is important as well as the search for parameters within the management's control. As a matter fact, the result in this study may not come as a surprise to a system dynamicist who knows very well that, complex systems exhibit counter intuitive behavior.

IV. CONTRIBUTIONS AND LIMITATIONS

After all, anyone driving automobiles for a while knows very well that, when negotiating sharp turns prudence lies in slowing down to negotiate the turns, or a loss of control is inevitable (a la, an unintended side effect). This outcome is more pronounced when driving with a trailer, which can be likened to a supply chain environment. In a supply chain environment, the organizations of retailer and his supplier are linked by way of the order information and the flow of goods between them and changes in either of them affect the other partner's system variables. Some contributions of this study are: a) highlights the need for the supply chain partners to understand the effect of defining the objective functions b) demonstrates that inventory policies can help accomplish the desired objective functions c) reaffirm the usefulness of information visibility and flexible workweek in stabilizing the production schedules d) and emphasizes that other complementary strategies like forecasting methods and inventory policies can enhance the effectiveness of information visibility policy.

Interests of both partners of the supply chain are served the best when each partner in the supply chain shares information with the other on real time basis and desists from making aggressive corrections that would result in destabilizing the smooth operation of the supply chain.

Limitations of the model: Although the model captures the typical supply chain behavior observed in the real world, there is no denying that the model is quite simplified compared to the complex real world. Following explicit assumptions helped simplify the model. a) Uniform shipping cost per unit, b) uniform ordering costs, c) decimal values allowed in the workforce numbers, d) supplier is assumed to be servicing a retailer and e) sufficient surplus capacities at supplier end assumed available.

Future studies: Further studies will focus on other obtaining more useful insights into other possible scenarios different patters of customer orders, like cyclic or seasonal trends.

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