A MULTI-AGENT APPROACH FOR ANALYSING MATERIAL FLOW IN A MANUFACTURING SUPPLY CHAIN

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ABSTRACT

In the last decade, supply chain operations have received tremendous attention in manufacturing and business sectors due to an increasingly challenging marketplace. This paper presents a multi-agent approach for analysing material flow in a manufacturing supply chain under information sharing. The model is capable of handling complex networks with many tiers, each tier with many business units and complex interactions among them. We have discussed the multi-agent architecture and run simulations for analysing the operational aspects under both deterministic and stochastic demand. This will allow companies to quantify different interacting parameters in the supply chain and support improvement in operations.

Key Words: *Supply Chain, Multi-Agent Approach, Material Flow.*

1. INTRODUCTION

A supply chain is "an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: (i) acquire raw materials /ingredients /components, (ii) convert these raw materials /ingredients /components into specified final products, and (iii) deliver these final products to retailers" (Beamon,1998). This chain is traditionally characterized by the flow of materials in forward direction and information and money in backward direction between the business entities. A supply chain is operated based on its existing business entities, and their facilities and networks.

In the last decade, supply chain management has become an important area due to an increasingly challenging marketplace. A particular problem with supply chains is known as demand amplification or Bullwhip effect in a supply chain occurring when slight to moderate demand uncertainties and variability become magnified when viewed through the eyes of management at each link in a supply chain (Russell and Taylor, 2003). A simple example of bullwhip effect can be found in Kimbrough *et al* (2002). Bullwhip effect, also called Demand amplification, Whip-saw, Whip-lash effect, or Forrester Effect (Lee *et al*, 1979a), was first described by Forrester (1961) but the experts at Procter & Gamble gave its name. Lee *et al* (1979a & b) identified five major causes of the bullwhip effect, including demand signal processing, non-zero lead time, batched order, rationing game under shortage, and price fluctuations and promotions. Consequently, such effects influence costs, inventory, reliability and other important business processes in upstream supply chain members.

The practical implication of this is the occurrence of various anomalous effects such as unusual stock levels, shortage of capacity for certain time periods, excessive variabilities in labour requirements, late deliveries and obsolescence. This can result in severe problems for companies operating upstream in the chain, which are often mainly system induced. This leads companies to invest significant amounts in inventory management and scheduling systems only to see little improvement in performance and profit. The only effective counter to the "Forrester effect" in supply chains is in the more effective communication flow, information sharing and integration along the supply chain. This in turn should result in a reduction of stock levels and lead times.

The previous research in this area focuses on demonstrating the existence of this phenomenon and identifies its possible causes (Chandra and Grabis, 2005; Chen *et al*, 2000; Kelle and Milne, 1999; Zhang, 2004; Liang and Huang, 2005; Lee *et al*, 2000; Holland and Sodhi, 2004; Pujawan, 2004; Potter and Disney, 2004 and Warburton, 2004). Research which attempts to quantify takes a very simplistic approach by assuming a simple two-stage supply chain e.g. a single retailer and a single manufacturer (Kelle and Milne, 1999; Zhang, 2004; Lee *et al*, 2000; Warburton, 2004 and Disney and Towill, 2003), which is inflexible due to the limited assumptions made and the focus on a single echelon of a supply chain (Potter and Disney, 2004). This approach does not reflect the current global manufacturing supply chain requirements. It is reported in the literature that the Bullwhip effect can be reduced or eliminated via information sharing along with a number of assumptions (Kimbrough *et al*, 2002 and Chen, 1999).

Traditionally, supply chain entities do not share the type and status of their inventory system with other entities, resulting in the bullwhip effect and difficulty in the control and forecast of inventories (Liang and Huang, 2005). This paper presents a multi-agent approach for analysing material flow, under information sharing and system thinking, of a manufacturing supply chain network. The model can handle complex networks with many stages (tiers) in the supply chain where each tier may contain many business units and complex interactions exist among the business entities. In addition, any number of products can be considered in the supply chain. Inclusion of wide ranges of forecasting methods and lot sizing policies is possible. In this paper, the main purpose is to develop a multi-agent architecture for supply chain operation and run the simulation for analysing the operational aspects under both deterministic and stochastic demands at the retailer's end. This will allow companies to quantify inventory holding cost, shortage cost, ordering /set-up cost, and other parameters for the entire chain for a chosen demand forecast method, batch sizing policy and known lead times. The outcomes of this research will also facilitate study of the Bullwhip Effect in a complex supply chain.

The paper is organised as follows. Following the introduction, we briefly discuss the supply chain structure considered in this research. In the following section, a multi-agent system and agent activities are described. After that simulation results and discussions are provided. Finally conclusions are presented.

2. SUPPLY CHAIN NETWORK

In this paper, we consider a supply chain with four stages namely suppliers, manufacturers, wholesalers (distributors) and retailers as follows.

As is shown in Figure 1, retailers sell the products directly to the market. At the other end, we assume that the suppliers have enough materials to deliver to the manufacturers. The activities of manufacturers can be divided into two types: (i) ordering, receiving and maintaining stocks of raw-materials, and (ii) manufacturing and maintaining stocks of finished products. The wholesalers would receive products from the manufacturers, deliver to the retailers, and maintain stocks of products when necessary. In this research, we consider a supply chain with multiple entities at each tier such as multiple suppliers, manufacturers, wholesalers and retailers. The network structure for this problem can be defined as shown in Figure 2. In addition, we also consider multiple products flowing through the network.

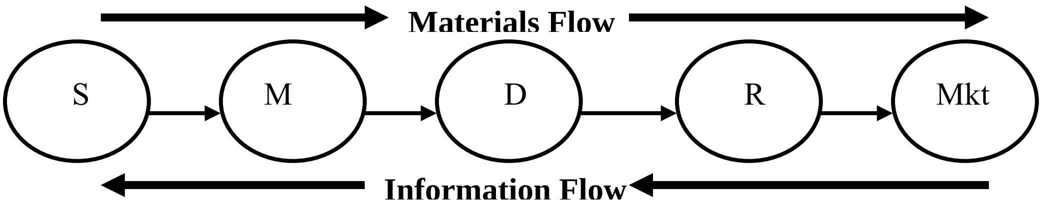

Figure 1. A simple supply chain diagram

(S = supplier, M = manufacturer, D = distribution centre, R = retailer and Mkt = market)

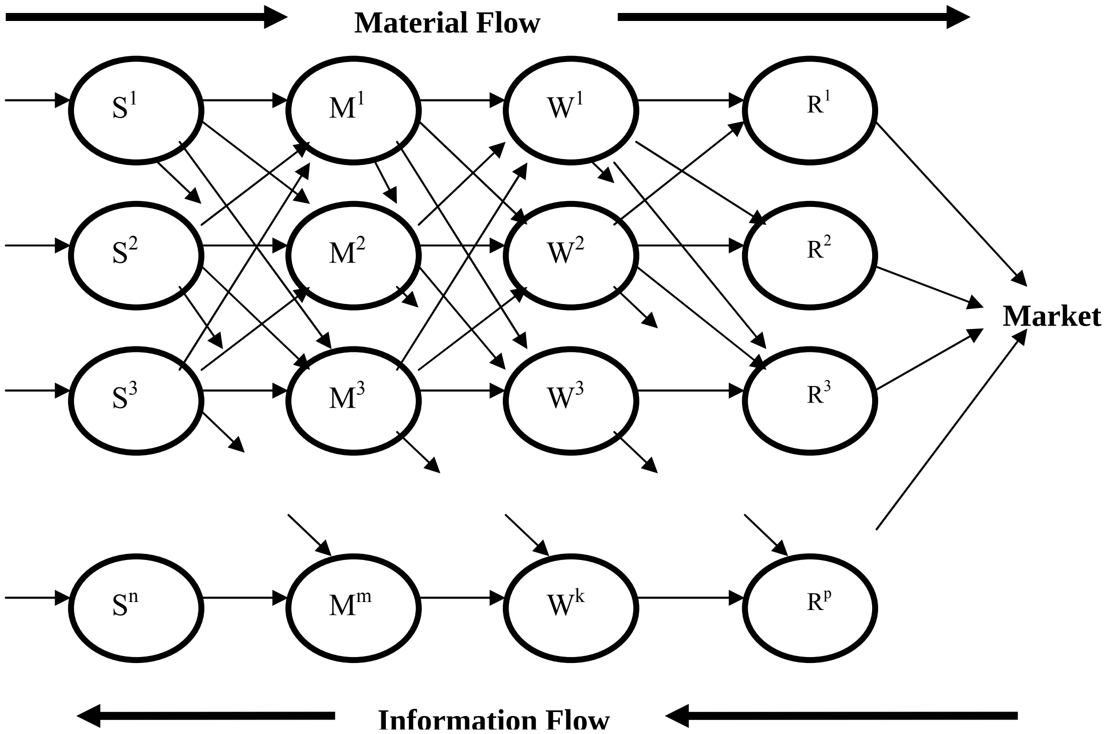

Figure 2. A Supply Chain with Multiple Entities in each Stage

3. AGENT AND MULTI-AGENT APPROACH

The multi-agent approach focuses on systems in which a number of intelligent agents interact with each other. The agents can be defined in different ways depending on the way they are implemented and the tasks they perform. As defined by Wooldridge and Jennings (1995), an agent should have the following properties:

- **Autonomy**: It should have some control over its actions and should work without human intervention.

- **Social ability**: It should be able to communicate with other agents and/or human operators.
- **Reactivity**: It should be able to react to changes to its environment.
- **Pro-activeness**: It should also be able to take initiative based on pre-specified goals.

The above mentioned properties are generic for an agent. However an agent may exhibit more of one property than another based on its architecture and embedded intelligence (Julka *et al*, 2002).

In any multi-agent system, the agents are considered to be autonomous entities. Their interactions can be either cooperative or selfish. That is, the agents can cooperate towards a common goal, or they can pursue their own self-interests. In such system, each agent has incomplete information or limited capabilities for solving the problem and, thus, has a limited viewpoint. A multi-agent system provides communication languages, interaction protocols, and agent architectures that facilitate study of the whole system.

4. MULTI-AGENT APPROACH IN SUPPLY CHAIN

Traditionally, supply chain management problems are distributive in nature and require extensive intelligent decision making. For example, the activities such as marketing, distribution, warehousing, manufacturing and purchasing along the supply chain are operated independently usually in different geographically dispersed locations. The objectives of these activities are often conflicting. For example, the marketing's objective is to maximize sales and customer services, whereas many manufacturing units are designed to maximize throughput and minimize item costs with little consideration for the impact on inventory level and distribution capabilities (Kaihara, 2003). This often creates shortages down stream in the supply chain resulting in customers' dissatisfaction. The purchasing contracts are often negotiated with very little information beyond historical purchasing patterns. Thus it is clear that there is a need for a single co-ordinated system for effective operation of any supply chain system. The integration of different entities in a supply chain can be made effectively using a multi-agent approach.

In any supply chain, the retailer, wholesaler, manufacturer, supplier or any other entity can be treated as an intelligent agent. In reality, they are autonomous heterogeneous agents. Agent activities in terms of product requirements and delivery lead to decision problems for agents. Each agent has its own models or algorithms to make its own decisions, has a number of parameters or indicators to express its status, has one or more suppliers and has one or more customers. For example, a retailer (an agent) will determine its market demand, calculate its own ordering quantity, place orders, receive products from the distributors, update its status, calculate cost and sell to the market. Each agent communicates only to a number of agents in its immediate right and left tiers for placing orders, receiving delivery, payment, receiving orders, fulfilling demands and other information sharing. The market demand information must flow from the left end to the right end along the chain. Any changes in demand, delivery and other conditions can easily be incorporated to any agent's decision problem for updating its decision. Finally, an individual agent's goal is to minimize its own operational costs and maximize customer services.

The above characteristics are common for all entities in the supply chain. For the supplier agent (at the left side of the chain), we assume it has an infinite stock and does not need to order from anyone or receive any supply. The retailer agent sells goods on demand and does not accept any order directly from the market; it fulfils the market demand from its inventory. We assume the lead time is zero for the retailer. That means, once the supply is received the goods are ready for sale to the market.

Previous work on an agent-based approach in the supply chain involves (i) a multi-agent framework for simple supply chain (Kimbrough et al, 2002, Piramuthu, 2005 and Janssen, 2005), chemical industry supply chain (Julka et al, 2002), planning vehicle transhipment (Fischer and Gehring, 2005) and supply chain coordination in construction (Xue et al, 2005); (ii) managing information flow for complex products (Framling et al, 2006) and for process industries (Garcia-Flores et al, 2000); (iii) negotiating the tradeoffs of acquiring different resources (Kaihara, 2001) and in a collaborative way for the global manufacturing supply chain network (Jiao et al, 2006), and (iv) demand forecasting (using genetic algorithm) as part of supply chain (Liang and Huang, 2005).

Garcia-Flores et al (2000) modelled the retailers, warehouses, plants and raw material suppliers as a network of cooperative agents for paints and coating production. In addition, they defined logistics and purchasing as agents. Liu et al (2005) developed a multi-agent framework where the business agents are: outsourcing, inventory, sales, production planning and customer service. Liang and Huang (2005) considered information sharing including forecasting knowledge and analysed the whole chain from the "systems thinking" point of view. Janssen (2005) considered a semi-cooperative coordination where suppliers and consumers have their own selfish goals, but also the common goal of creating an efficient and effective supply chain. The agents in their model are production, warehouse and dealer or supermarket. Our multi-agent architecture considers four agent classes with full information sharing. These are retailer, wholesaler, manufacturer and supplier. The activities such as logistics, purchasing, inventory, sales, forecasting, and transportation are defined as agents' activities.

5. AGENT ACTIVITIES IN SUPPLY CHAIN

The models and procedures used by the agents at each stage are briefly discussed in Table 1.

Table 1. Agent Characteristics

An Agent			
Models	Own status	Suppliers	Customers
- Forecasting - Reorder quantity - Lead time stock - Inventory policy - Costing & cost functions - Supplier selection	- Number of products - Inventory level for each product - Safety stock for each product - Shortage cost for each product - Holding cost for each product - Capacity (storage and /or Production, handling, etc.)	- Lead time for each product - Ordering cost for each product - Time of placing an order and ordering quantity - Time of delivery and delivery quantity - Service history (reliability of service and dependency)	- Demand for each product - Time of placing an order and ordering quantity - Time of delivery and delivery quantity - Transportation cost for each product

The retailer agent uses a simple moving average method for forecasting market demand. The agent uses an economic order quantity method for finding its reorder quantity and follows a continuous inventory policy with the following parameters:

- A maximum inventory level of (Q_R+s), where Q_R is the ordering quantity and s is the safety stock.
- Order for Q_R quantity once the stock reaches (L_R*D+s) quantity, where L_R is the supply lead-time and D is the demand rate.
- Receive delivery of an order after L_R periods

The inventory level and shortages are calculated as follows:

- Inventory level, $I_t = I_{t-1}$ + (Order received)$_t - D_t$, for $I_t \geq 0$, where I_t and D_t are the inventory level and demand at period t respectively. We must mention here that the order received may be different from the ordering quantity for some reasons.
- Shortage, $SH_t = |I_t|$ if $I_t < 0$

The retailer would select its preferred supplier based on supply reliability, business preference, geographical proximity and any other retailer imposed indicator. The agent will calculate its cost based on the following equations:

Inventory cost: At the end of every time period, it would record the stock I_t for each product. The inventory holding cost will then equal $\sum_{t=1}^{T} H * I_t$.

Ordering cost = (total number of order in time T) * (ordering cost per order).

Shortage cost = $\sum_{t=1}^{T} SC * SH_t$

Where,

SH_t = shortage quantity in each period and

SC = shortage cost per unit per unit time.

Transportation cost = (number of units to be shipped)*(unit transportation cost). Note that the transportation cost is usually a part of product delivery of a previous stage in the chain.

The warehouse (distributor) agent has activities similar to a retailer agent. The manufacturers' activities can be divided into two parts: (i) ordering and receiving materials from the suppliers and (ii) manufacturing and holding the products. The two activities are combined in the behaviour of the manufacturer agent. Although the activities of the first part are very similar to the retailer and warehouse agent, the raw-material ordering quantity may be directly associated with the manufacturing quantity. In the second part, the ordering quantity (also known as manufacturing quantity) calculation requires us to consider the manufacturing unit capacity.

5. MULTI-AGENT SIMULATION

The simulation code is developed in Java. The simulation time step (clock update) is a parameter which can be varied, but is set as one day. After each time step, the simulation runs for each agent from the right of the chain to the left. For each agent, the steps of the simulation algorithm are very similar, as is briefly discussed below.

- At $t = 0$, initialize all parameters and take required inputs
  - Forecast demand
- At any time $t > 0$, for each retailer, then for each wholesaler, then for each manufacturer, and then for each supplier:
  - Update forecast
  - Update inventory level if there is any change due to items sold or delivery received
  - If the stock is below the re-order point, determine ordering quantity and place an order
  - When ordering, follow the supplier selection rules
  - If there is any shortage, update the shortage quantity
- At $t = T$ (end of simulation), generate output

After running the simulation for a given number of time steps, the detailed results are stored in tabular form. From the detailed results, the summary results are generated for analysis. Sample results will be provided in the next section.

The simulation model requires a huge amount of data for market demand. The manual entry of such data would be a very tedious task, so we have decided to read those data from an input file. For convenience of experimentation, we developed an HTML file with a Java applet so that interested researchers can experiment with the model on the internet. It must be noted that this experiment would be carried out for a given demand data set and one product only. However, the full version allows any demand data and can handle any number of products. In arbitrarily setting data for experimentation, one must be consistent about holding, shortage and product costs, as these costs increase with every stage passing (from left to right) in the supply chain. In reality, holding and shortage costs are functions of product cost. The outputs include ordering cost, inventory holding cost, shortage cost, and ordering quantity for each agent.

6. EXPERIMENTAL RESULTS AND DISCUSSIONS

To demonstrate the use of the developed multi-agent approach for a supply chain operation, we run the simulation considering one linear chain as of Figure 1 with one product in this section. The data used for a test case is as follows.

Table 2. Data for a test case

	Agent			
Item	Retailer	Wholesaler	Manufacturer production	Manufacturer raw material
Estimated yearly demand	12000	-	-	-
Initial inventory (quantity)	100	500	600	600
Maximum inventory level	600	800	700	800
Re-order inventory level	100	200	200	200
Safety stock	100	100	200	200
Production rate (units/day)	-	-	80	-
Lead time (in days)	1	1	1	1
Ordering /setup cost ($/order)	50	70	70	60
Holding cost ($/unit/day)	6	5	4	3
Shortage cost ($/unit/day)	5	4	3	2

Two sets of experiments were run: (i) first with constant demand of 48 units in each time period and (ii) then a variable demand for each day where the average is 48 units with a standard deviation of 20. We ran the simulation for 300 time steps by changing the ordering and setup costs of each agent. In our experiments, for convenience of comparisons we change the setup /ordering cost of agents one at a time. We use the economic order quantity formula to find Q_R for all agents in our experiments. The results of these two sets of experiments are presented in the following two tables.

Table 3. Simulation outputs with constant demand

Agent	Ordering /Setup cost	Total cost (million $)	Total inventory	Total shortage	Number of orders
Retailer	50	2.324	84025	0	33
	100	2.471	110325	0	23
	150	2.571	134597	0	19
	200	2.795	151769	0	17
Wholesaler	70	2.324	139425	1467	25
	100	2.375	155903	1234	21

	130 155	2.454 2.597	166633 179223	1216 926	19 17
Manufacturer production	70 110 150 175	2.324 2.426 2.434 2.526	148308 185992 194292 221102	2907 2178 1512 1451	22 18 15 14
Manufacturer's supplies	60 110 140 150	2.324 2.416 2.439 2.495	169140 200564 206842 224850	2392 2108 2008 1857	21 15 14 13

Table 4. Simulation outputs with variable demand

Agent	Ordering /Setup cost	Total cost (million $)	Total inventory	Total shortage	Number of orders
Retailer	50 100 150 200	2.312 2.486 2.559 2.798	83125 113306 133624 150686	0 0 0 0	33 23 19 17
Wholesaler	70 100 130 170	2.312 2.386 2.461 2.733	138465 157437 168255 229554	1467 1234 1167 0	25 21 18 16
Manufacturer production	70 110 130 150	2.312 2.424 2.439 2.441	150279 184743 184190 196629	3078 2178 1557 1512	23 18 16 15
Manufacturer's supplies	60 90 120 140	2.312 *2.296* 2.357 2.420	169624 *160616* 178605 201390	2392 *2608* 2369 2038	21 17 15 13

As we can see in Table 3, for each agent, the total cost increases and the number of orders decreases with the increase of ordering /setup cost as expected. A higher ordering /setup cost reduces the number of orders by increasing the order size. As a consequence, the cumulative inventory increases for all agents. Higher inventory lowers the shortages. As in Table 3, the cumulative shortage decreases with the increase of ordering /setup cost except for the retailer agent. This is due to the fact that our objective is to minimize the shortage at the retailer end and the retailer demand dictates the activities in the upstream of the supply chain. From that table, it is evident that the inventory and shortage level slowly amplifies (in general term) for the agents of upstream in the chain. Similar patterns are observed in Table 4 with variable demand except the results with an ordering cost of $90 for the manufacturer's supplies agent. We believe this is due to effect of random demand generation. However, no significant changes have been observed because of demand variability.

The inventory levels for different agents are plotted in the next four figures. As there is no significant difference between the first, second and third 100 time steps, we are reporting only for the first 100 time steps. Figure 3 and 4 represent the inventory levels with constant and variable demand, for the case problem shown in Table 2.

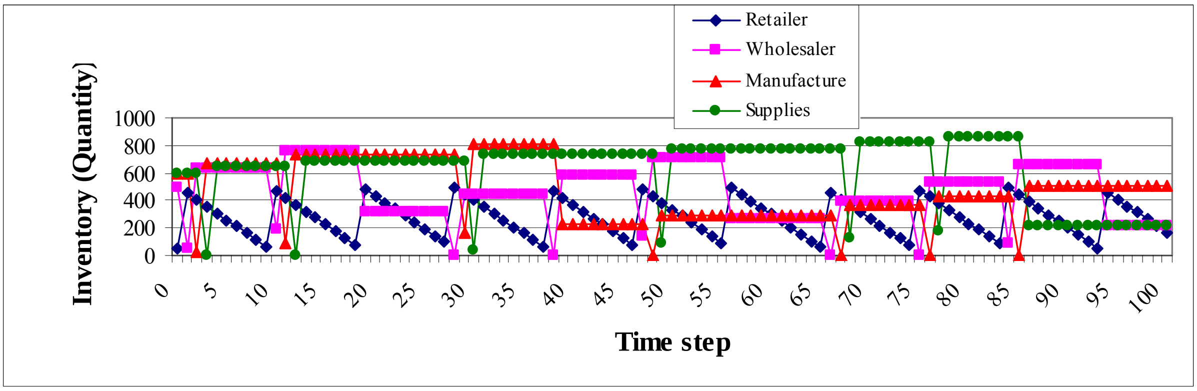

Figure 3. Inventory level with constant demand of 48 units

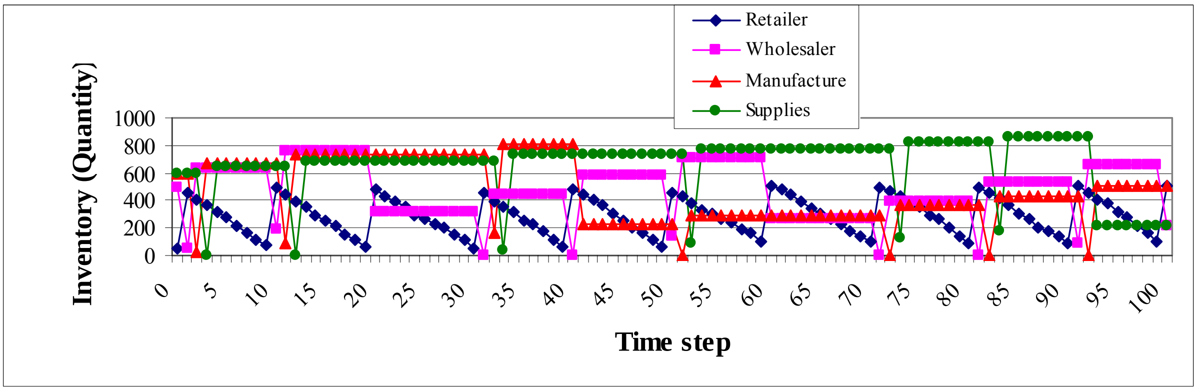

Figure 4. Inventory level with variable demand with an average of 48 units and standard deviation of 20

The above experiments were also run with a different demand by keeping the ordering quantity fixed as the case problem discussed in Tables 2 – 4. That means the ordering quantity is not calculated using the economic ordering quantity formula based on new demand data. The purpose of this experiment is to examine the effect of arbitrary fixed ordering quantity on the total costs and inventory levels. The plot in Figure 5 shows the inventory levels with constant demand of 120 units per day. Other data are similar to the case problem shown in Table 2.

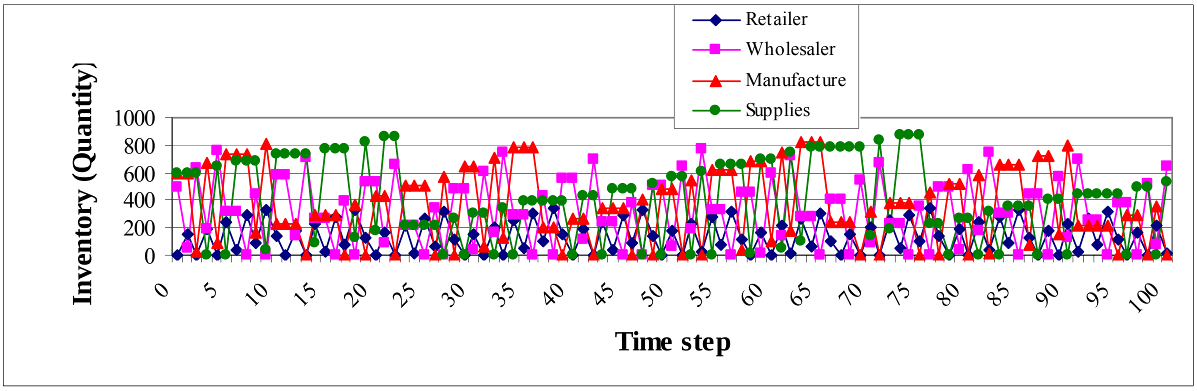

Figure 5. Inventory level with constant demand of 200 units

The plot in Figure 6 shows the inventory levels with variable demand with an average of 120 units per day and standard deviation of 20. Other data are similar to the case problem shown in Table 2.

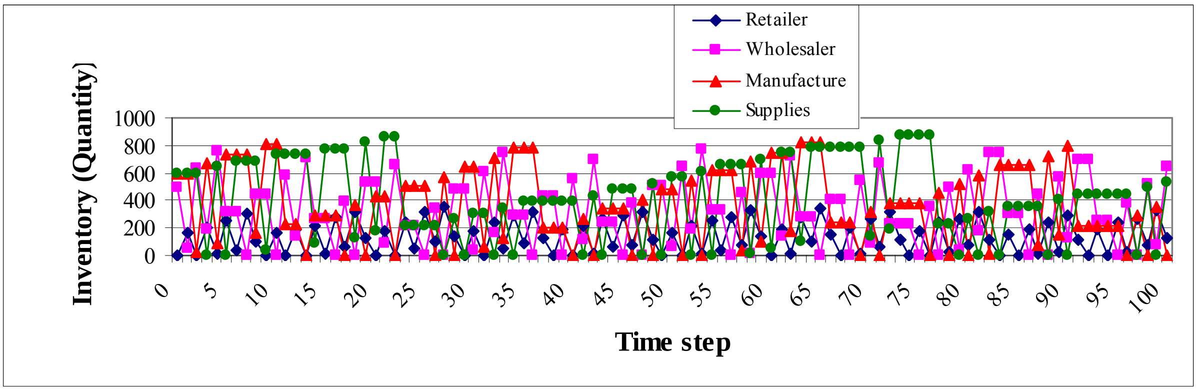

Figure 6. Inventory level with variable demand with an average of 200 units and standard deviation of 20

In Figures 3-6, no significant differences are observed due to demand variability and increase of demand. We believe this is because of information sharing among all the agents in the chain. Although, the experimental results with *multiple agents in each tier* of the supply chain report similar behaviour, we are performing further experimentation with a wide range of parameter settings, and different ordering and inventory policies.

7. CONCLUSIONS

We present a multi-agent framework for analysing manufacturing supply chain operation under information sharing. The model is capable of handling complex networks with many stages, each stage with many business units and complex interactions among them. We have discussed the multi-agent architecture and run a simulation for analysing the operational aspects. This will allow companies to quantify different interacting parameters in the supply chain and help to make improvement in operations. Two cases of supply chain were tested and their results give confidence that the model exhibits realistic behaviour.

REFERENCES

Beamon, B. M. (1998), Supply Chain Design and Analysis: Models and Methods, *International Journal of Production Economics*, **55**, 281-294.

Chandra, C. and Grabis, J. (2005), Application of Multi-steps Forecasting for Restrining the Bullwhip Effect and Improving Inventory Performance under Autoregressive Demand. *European Journal of Operational research*, **166**, 337-350.

Chen, F. (1999), Decentralized Supply Chains Subject to Information Delays, *Management Science*, **45**, 1076-1090.

Chen, F., Drezner, D., Ryan, J. K. and Simchi-Levi, D. (2000), Quantifying the Bullwhip Effect in a Simple Supply Chain: the Impact of Forecasting, Lead Time and Information, *Management science*, **46**, 436-443.

Disney S. M. and Towill, D. R. (2003), On the Bullwhip and Inventory Variance Produced by an Ordering Policy. *Omega,* **31**, 157-167.

Fischer, T. and Gehring, H. (2005), Planning Vehicle Transhipment in a Seaport Automobile Terminal using a Multi-agent System, *European Journal of operational Research*, **166**, 726-740.

Forrester, J. W. (1961), *Industrial Dynamics*, Cambridge, Massachusetts: MIT Press.

Framling, K., Ala-Risku, T., Karkkainen, M. and Holmstrom, J. (2006,) Agent-based Model for Managing Composite Product Information, *Computers in Industry*, **57**, 72-81.

Garcia-Flores, R., Wang, X. Z. and Goltz, G. E. (2000), Agent-based Information Flow for Process Industries' Supply Chain Modelling, *Computers and Chemical Engineering,* **24**, 1135-1141.
Holland, W. and Sodhi, M. S. (2004), Quantifying the Effect of Batch Size and Order Errors on the Bullwhip Effect using Simulation. *International Journal of Logistic: Research and Applications*, **7**, 251-261.
Janssen, M. (2005), The Architecture and Business Value of a Semi-cooperative, Agent-based Supply Chain Management System, *Electronic Commerce Research and Applications*, **4**, 315-328.
Jiao, J., You, X. and Kumar, A. (2006), An Agent-based Framework for Collaborative Negotiation in the Global Manufacturing Supply Chain Network, *Robotics and Computer Integrated Manufacturing*, In press.
Julka, N., Srinivasan, R. and Karimi, I. (2002), Agent-based Supply Chain Management – 1: Framework, *Computers and Chemical Engineering,* **26**, 1755-1769.
Kaihara, T. (2003), Multi-agent Based Supply Chain Modelling with Dynamic Environment, *International Journal of Production Economics*, **85**, 263-269.
Kaihara, T. (2001), Supply Chain Management with Market Economics, *International Journal of Production Economics*, **73**, 5-14.
Kelle, P. and Milne, A. (1999), The Effect of (s,S) Ordering Policy on the Supply Chain. *International Journal of Production Economics*, **59**, 113-122.
Kimbrough, S., Wu, D. J. and Zhong, F. (2002), Computers Play the Beer Game: Can Artificial Agent Manage Supply Chains?, *Decision Support Systems*, **33**, 323-333.
Lee, H. L., Padmanabhan, V. and Whang, S. (1997a), Information Distribution in a Supply Chain: The Bullwhip Effect. *Management science*. **43,** 546-558.
Lee, H. L., Padmanabhan, V. and Whang, S. (1997b), Bullwhip Effect of the Supply Chain. *Sloan management review*, **38**, 93-102.
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**, 626-643.
Liang, W.-Y. and Huang, C.-C. (2005), Agent-based Demand Forecast in Multi-echelon Supply Chain, *Decision Support Systems*, In press.
Liu, J., Zhang, S. and Hu, J. (2005), A Case Study of an Inter-enterprise Workflow-supported Supply Chain Management System, *Information & Management*, **42**, 441-454.
Potter, A. and Disney, S. M. (2004) Bullwhip and Batching: an Exploration. *International Journal of Production Economics*, 1-11.
Pujawan, I. N. (2004), The Effect of Lot Sizing Rules on Order Variability. *European Journal of Operational research*, **159**, 617-635.
Piramuthu, S. (2005), Machine Learning for Dynamic Multi-product Supply Chain Formation, *Expert Systems with Applications*, **29**, 985-990.
Russell, R. S. and Taylor III, B. W. (2003), *Operation Management*. Fourth ed. 2003, NJ: Prentice Hall. 267.
Warburton, R. D. H. (2004), An Analytical Investigation of the Bullwhip Effect. *Production and operations management*, **13**, 150-160.
Xue, X., Li, X., Shen, Q. and Wang, Y. (2005), An Agent-based Framework for Supply Chain Coordination in Construction, *Automation in Construction*, **14**, 413-430.
Zhang, X. (2004), The Impact of Forecasting Methods on the Bullwhip Effect. *International Journal of Production Economics*, **88**, 15-27.