Investigating Impact of Intelligent Agents in Improving Supply Chain Performance

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ABSTRACT

Improvement in supply chain performance is one of the major issues in the current world. Lack of coordination in the supply chain is the main drawback of supply chain that many researchers have proposed different methodologies to overcome it. VMI (Vendor-managed inventory) is one of these methodologies that implementing it has some obstacles. This paper proposes new model that is agent-managed SC. This paper is trying to use intelligent agent technology in the supply chain. In this paper supply chain assessment performance measure indicators have been divided into three categories; cost, flexibility and customer responsiveness indicators. In the first category we use holding and backordered inventory costs, for second category, bullwhip effect are used and for the last one customer responsiveness indicator has been applied. Bullwhip effect is one of the main phenomena's that has been tried to reduce it with the agent-based systems.
Method of this research is discrete event simulation. In this paper, three echelon supply chain performances, without intelligent agents, have been studied and performance indicators have been measured, after that, we introduce agent-based supply chain and in the new model, performance indicators have been measured and compared with the basic model. This paper demonstrates the performance of intelligent agents in the improvement of supply chain performance indicators.

1. Introduction

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only the manufacturers and suppliers, but also the transporters, warehouses, retailers and even the customers themselves. Supply chain designing, planning and operation decisions play a significant role in the success or failure of a firm [7].

A supply chain lacks coordination if each stage optimizes only its local objective, without considering the impact on the complete chain. Total supply chain profits are, thus, less than what could be achieved through coordination. Each stage of the supply chain, in trying to optimize its local objective, takes actions that end up hurting the performance of the entire supply chain [5].

An agent is a computer system that is situated in some environment and that is capable of autonomous action in this environment in order to meet its design objectives [24]. Normally, an agent will have a repertoire of actions available for that. These sets of possible actions represent the agents' capability: its ability to modify its environments.

When do we consider an agent to be intelligent? The question, like the question 'what is intelligence?' One way of answering is to list the kinds of capabilities that we might expect an intelligent agent to have. The following list is suggested conditions for intelligent agents [24]:

- Reactivity: Intelligent agents are able to perceive their environment, and respond in a timely fashion to changes that occur in it in order to satisfy their design objectives.
- Proactiveness: Intelligent agents are able to exhibit goal-directed behavior by taking the initiative in order to satisfy their design objectives.
- Social ability: Intelligent agents are capable of interacting with other agents in order to satisfy their design objectives

Vendor-managed inventory (VMI) is a new methodology that proposed to establish coordination in the supply chain. With VMI, the manufacturer or supplier is responsible for the decisions regarding to product inventories at the retailer. As a result, the control of the replenishment decision moves to the manufacturer instead of the retailer. VMI requires the retailer to share demand information with the manufacturer to allow it to make inventory replenishment decisions [5].

There are obstacles to coordinate and implement these methodologies (e.g. VMI) in the supply chain. Some of these obstacles are incentive obstacles, operational obstacles and behavioral obstacles.

In this paper, a new Agent-managed supply chain methodology has been proposed to overcome these obstacles, with using advantages of such methodologies, which can help supply chain to improve its performance indicators.

2. Literature Review

One of the most important factors in the supply chain is bullwhip effect. The tendency of orders to increase in variability as one moves up into a supply chain is commonly known as the bullwhip effect [6]. The first recognition of the bullwhip effect can be traced back to forrester (1958, 1961), and kahn (1987) also found evidence of inventory volatility similar to the bullwhip effect [31]. The well-known beer game originated from MIT at the end of the fifties and sterman(1989) reports on the major findings from a study of the performance of some 2000 participants. Kaminsky and Simchi-Levi (1998), Kaminsky et al.(2000) developed a computerized version of the beer game [6]. It has been shown that the variance increases linearly in echelon stages with information sharing but

exponentially in echelon stages without information sharing. Purpose of information sharing is that the customer demand at the lowest node of the supply chain is immediately transmitted to all upstream nodes. Information sharing is what chen et al. call centralized demand information [27].

Lee et al. state that there are five fundamental causes of bullwhip; non-zero lead time, demand signally processing, price variations, rationing and gaming, and order batching, to which other proven sources may be added [8].

Chen et al. made an important contribution in recognition the role of demand forecasts as a filter for the bullwhip effect. Using a first-order autoregressive process for describing demand similar to Lee et al., they derived a lower bound for the bullwhip effect in a two-stage serial supply chain when the downstream retailer uses the moving average method to forecast lead time demand. In a sequel, Chen et al. extended their results to the case which a simple exponential smoothing method is used to forecast lead time demand [25].

In the other research, the impact of forecasting method on the bullwhip effect for a simple replenishment system has been considered. In this system a first-order autoregressive process which describes the customer demand and an order-up-to inventory policy that characterizes the replenishment decision have been considered. The findings of this research indicate that different forecasting methods lead to bullwhip effect measures with distinct properties in relation to lead time and underlying parameters of the demand process [25].

Other research considers a k-stage supply chain. The customer demands are independent and identically distributed random variables. The last stage observes customer demand D and places an order q to previous stage. All stages place orders to the previous stage in the chain. The orders are received with lead-times L_i between stages i and i+1. The stages use the moving average forecast model with p observations. To quantify the increase in variability, it is necessary to determine the variance of orders q^k related to the variance of demands D.it has been shown that in case of decentralized information the variance increase is multiplicative at each stage of the supply chain [10]:

$$\frac{Var(q^k)}{Var(D)} \geq \prod_{i=1}^{k} \left(1 + \frac{2L_i}{p} + \frac{2L_i^2}{P^2}\right) \tag{1}$$

And in the case of centralized information, the variance increase is additive [9]:

$$\frac{Var(q^k)}{Var(D)} \geq 1 + \frac{2\left(\sum_{i=1}^{k} L_i\right)}{P} + \frac{2\left(\sum_{i=1}^{k} L_i\right)^2}{P^2} \tag{2}$$

Moyaux et al. separate demand into original and adjustments. They describe two principles explaining how to use the shared information to reduce amplification of order variability induced by lead times [23].

Cao et al. present a systematic approach to tackle the issue of the bullwhip effect in supply chain management. They proposed a multi-agent supply chain framework for achieving this goal [5].

Li et al. provide a review of coordination mechanisms of supply chain systems. This framework highlights the behavioral aspects and information needs in the coordination of a supply chain [19].

Gao et al. consider a two-period, two part supply chain consisting of one supplier and multi-retailer. They study the effect of stock sharing among retailers on the supply chain. They analyze the effect of stock sharing mode and also the traditional mode without stock sharing on retailers, supplier and the whole supply chain's performance [13].

There are different researches that use these frameworks for different industries such as construction industry or electric industry. Refer to [12],[30]. As we can see, there are different works that analyze the effects of coordination in the supply chain, but each of them studies this problem from a specific viewpoint, and we have not seen a report with total approach. We try to propose a specific tool (intelligent agents) for coordination in supply chain, designing agent based system with specific methodology, use different performance categories and present related simulation results with and without proposed tool.

The next research measures the variance amplification of orders within order-up-to policies from a control engineering perspective. It proves that classical order-up-to policies will always generate a bullwhip effect. It is however, possible to dampen order fluctuations even in environments where decision makers have to rely on forecasts [6]. Some of other researches have been done to apply agents in mechanical systems. In one research a set of agents is introduced to control an automated manufacturing environment. The architecture includes functions at the manufacturing cell level, materials handling and transport level and factory scheduling level. This research focuses on the functions of the agents of the transport system, which is composed of a set of AGVs [8].

Another research presents a multi agent system for the control of manufacturing systems. In this research, a new approach for establishing a multi-agent based system is presented for the control of manufacturing systems. In the proposed model, a multi-agent system architecture is established to accommodate a group of reactive agents according to the configuration of the manufacturing system [28].

One of the application of agents is in the new manufacturing systems. The fractal manufacturing system (FrMS) is one of the new manufacturing paradigms that is flexible, adaptable and reusable. The FrMS is composed of a number of "basic components", each of which consists of five functional modules: (1) an observer, (2) an analyzer, (3) an organizer, (4) a resolver and (5) a reporter. Each of these modules, using agent technology, autonomously cooperates and negotiates with others while processing its own jobs. A research focuses on formal modeling of agents and fractal-specific characteristics that provides a foundation for the development of the FrMS [22].

Another application of agents is on the planning of decision making. There is a research that focuses on the low level planning, where the multi-agent solution towards a "job-machine" assignment is considered. The main point of the discussion is the flexibility of planning systems ensured by the concept of agents "roles" and "emergencies" [14].

There is another research that introduces a framework which integrates process planning and production scheduling, as a means to achieve agile manufacturing. [17]. There are several researches that discuss about agent based supply chain. One research is as a contribution to the understanding of how to design learning agents to discover insights for complicated systems, such as supply chain [25]. The next research proposes a multi agent system to control ordering quantity for every echelon and find minimal total cost of entire supply chain. In this research, to forecast, a mechanism using real-coded genetic algorithm (RGA) is introduced to forecast the optimal solution and determine ordering quantity for every echelon [16].

In this paper it has been tried to use intelligent agents in a three echelon supply chain with determined strategies and measure the performance of supply chain before and after using agents. Discrete event simulation tool for measuring performance of supply chain has been used. The remainder of the paper is organized as follows: In section 3 performance indicators that have been used to measure supply chain performance are introduced. In section 4 we provide an overview of the simulation study. In section 5, the initial model and its assumptions are presented. In section 6 the results of simulation of initial model and its performance indicators have been presented. In section 7, the improved model with the intelligent agents, the methodology of designing multi agent system and the required agents are given. In section 8 the results of simulation and running models and comparison of the performance indicators of initial and improved model have been presented. Finally, a conclusion has been drawn, results of two model analyzed and insights presented in this paper.

3. Supply Chain Performance Indicators

In order to understand the supply chain and its characteristics, relevant performance indicators must be identified. Beamon [2] provides a literature survey of performance indicators used in supply chain

environments. Two types of performance indicators dominate; namely cost and customer responsiveness. Costs may include inventory and operating costs. Customer responsiveness measures include lead-time, stock-out probability, and fill rate.

Some recent sources of supply chain modeling and simulation not included in the Beamon [1,2] study are Berry & Naim, Li & Brien, Bhaskaran, Petrovic [3,15,4,21].

They also follow the main stream of using cost and some customer responsiveness measure. Berry and Naim [3] and Li and O'Brien [15] provide analytical models of supply chains. Berry and Naim [3] use customer service level, stock and production costs, in a case-based supply chain redesign effort involving just-in-time manufacturing, interplant planning and logistics integration, vendor integration, and time-based management.

Li and O'Brien [15] use four performance criteria; profit, lead-time, delivery promptness, and inventory cost, when proposing a hierarchical approach to supply chain modeling. When simulating supply chains, Bhaskaran [4], and Petrovic et al. [26] use subset of these performance indicators. Bhakaran [4] uses inventory levels as performance indicator when studying the impact of forecast errors and the use of MRP versus Kanban, in a stamping pipeline at an autonomous plant. Petrovic et al. [21] use total cost and fill-rate when simulating a made-up, serial supply chain with infinite capacity.

Beamon [2] advocates the use of a mix of measures, representing resources, output and flexibility, rather than relying on a single measure. Resource measures should indicate a high level of efficiency and may include cost and inventory.

Output measures aim at a high level of customer service and may include customer responsiveness, quality, and quantity of product produced. Resource measures, output measure and flexibility measure are used. Resource measures include cost and inventory that summarize inventory holding cost and backorder cost. The aim of output measure is high level of customer service and include order fill rate. Order fill rate is the fraction of orders that are filled from available inventory.

In a multiproduct scenario, an order is filled from inventory only if all products in the order can be supplied from the available inventory. The goal of flexibility measures is to indicate the ability to respond to a changing environment. Bullwhip effect is used as flexibility measure.

In this paper supply chain assessment performance measure indicators have been divided into three categories; cost, flexibility and customer responsiveness indicators. Financial indicator that is cost of supply chain including holding and backordered inventory costs, flexibility indicator that is bullwhip effect measure and customer responsiveness indicator that is order fulfillment rate.

Tab. 1. Different proposed performance indicators

No.	Researcher	Proposed performance indicator
1	Beamon(1998)	Cost and customer responsiveness
2	Berry and Naim(1996)	Customer service level, stock and production costs
3	Li and O'Brien(1999)	Profit, lead time, delivery promptness and inventory cost
4	Bhaskaran(1998)	Inventory level
5	Petrovic(1998)	Total cost and fill rate

4. Simulation Study

Discrete event simulation models can handle stochastic behavior throughout the supply chain. The simulation methodology and basic steps of the simulation process are as follow:

- Project planning
- Conceptual modeling
- Conceptual model validation
- Modeling
- Verification
- Validation
- Sensitivity analysis
- Experimentation and analyzing output data
- Implementation

Of vital importance are the validation and verification activities. If these activities fail to correct all model errors, the result of the simulation study can be questionable [20].

5. Initial Model

Initial model proposed in this paper is three echelon supply chain including manufacturer, distributor and retailer. Order-up-to policy for inventory replenishment is used. In this method ordering quantity is formulated as follows:

$$S = \overline{D}.\overline{L} + Z_\beta.\delta_D.\sqrt{L} \qquad (3)$$

$$IP = OH + SR - BO \qquad (4)$$

$$Q = S - IP \qquad (5)$$

Where S: reorder point; $\overline{D}$: demand average per period; $\overline{L}$: lead time average per echelon; Z: service level (z value of normal distribution); c_D: demand standard deviation per period; OH: number of units in on-hand inventory; SR: scheduled receipt; BO: number of units that backordered; Q: ordering quantity; IP: inventory position.

Initial model's process starts with the customer's needs input to the model, and this flow go up in the system toward the manufacturer.

Every echelon has data transfer with previous and next echelon, and whole system has no integrity. In this model every echelon checks inventory state at the end of each period and decides based on its own inventory level without considering other echelons status.

$$Demand_t = base + slope \times t + \sin(\frac{2\pi}{seasoncycle} \times t) + \quad (6)$$

$$noise \times Snormal()$$

Special method should be used to predict customer demand. Following formula is used to generate demand values during several periods:

Where $Demand_t$: demand value during t period;

Snormal: standard normal random number generator and seasoncycle is 7. Left parameters in the above mentioned formula make different patterns. Four demand patterns can be made as follows:

Tab. 2. Demand patterns in the mentioned formula

Demand Pattern	base	slope	season	noise
CON	1000	0	0	100
SEA	1000	0	200	100
SIT	551	2	200	100
SDT	1449	-2	200	100

CON2 has no seasonal and trend characteristics, SEA3 has seasonal characteristics, SIT4 has seasonal characteristic and increasing trend and SDT5 had seasonal and decreasing trend. SEA pattern for our simulation is used in this paper.

One of the critical steps of simulation is verification and validation. In order to verify this model, we used cross checking the model. The new model has been rechecked by another researcher. In this paper, a research which is based on control system engineering is used for our model validation.

This research measures the variance amplification of orders within order-up-to policies from a control engineering perspective. According to this point that two method assumptions are the same, two set of data for two methods in 30 times running models for bullwhip effect are compared and hypothesis tests for this two set of data are done. P-value for this test is 0.34 and then equality of two data set averages is accepted. Bullwhip effect, echelons inventory and cost and lead time are indicators that are measured in this model.

In table 3, 4 the bullwhip effect with two forecasting methods that are moving average and exponential methods, are shown in Fig.1 this performance indicator for two methods compared.

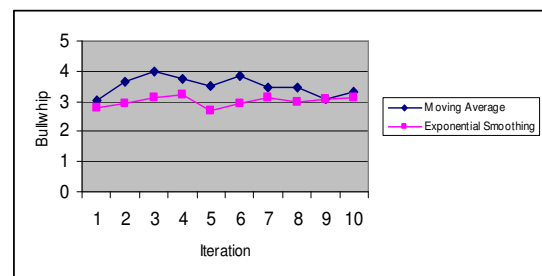[2] *Constant trend*
[3] *Seasonal trend*
[4] *Seasonal increasing trend*
[5] *Seasonal decreasing trend*

Tab. 3. bullwhip effect measures with moving average forecasting method

Run	1	2	3	4	5	6	7	8	9	10
Bullwhip	3.05	3.67	4.00	3.73	3.53	3.86	3.48	3.47	3.10	3.31

Tab. 4. bullwhip effect measures with exponential smoothing forecasting method

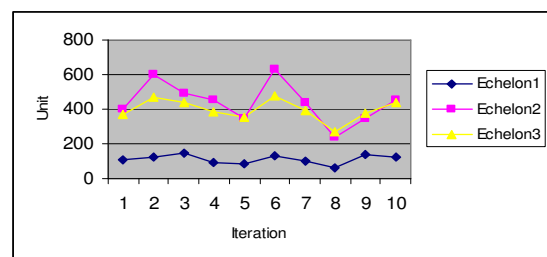| Run	1	2	3	4	5	6	7	8	9	10
Bullwhip	2.77	2.95	3.14	3.24	2.69	2.93	3.14	2.96	3.06	3.12

Fig. 1. Comparing bullwhip effect with two forecasting methods

Findings show effect of the forecasting method on supply chain performance.

Inventory level along the supply chain with exponential forecasting method is measured. In table 5, on hand inventory average in three echelons of supply chain during 10 Run of simulations is shown, and in Fig. 2 measures for three echelons compared:

Tab. 5. On-hand inventory average in supply chain

Run	1	2	3	4	5	6	7	8	9	10
Ech1	104	121	142	91	82	134	96	60	138	120
Ech2	400	601	493	455	343	632	437	240	345	450
Ech3	367	472	435	383	357	478	394	270	379	435

Fig. 2. On-hand inventory average in supply chain

In Fig. 2 the first line from the lower part of the diagram is echelon one and the next lines are echelon 2 and 3. This figure shows that along moving up through supply chain, inventory level average and its oscillation is going up and its reason is for cumulating of forecasting errors along moving up in the supply chain. Effect of lead time on bullwhip effect is studied. Fig. 3 shows the bullwhip effect in one supply chain with different amounts of lead time that are as follows:

1. Lead time has uniform distribution less than 1 period per echelon
2. Lead time has uniform distribution between 2 to 3 period per echelon
3. Lead time has uniform distribution between 5 to 6 period per echelon

Fig. 3 shows that with increasing the lead time amount, the bullwhip effect is going up suddenly. It can be seen that average of bullwhip effect measures in the whole of supply chain state one is 3.54, in state 2 is 4.41 and in state 3 is 19.48.
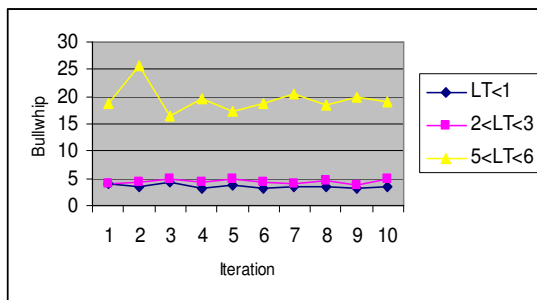

Fig. 3. Bullwhip effect measured in three state

6. Improved Model

Analysis of the initial model performance indicators shows that this system has several weak points. We should find approaches for removing causes of these problems such as bullwhip effect, high level of echelons inventory and cost while simultaneously increasing customer satisfaction indicators including order fill rate. Multi agent system characteristics such as data sharing and their reactive and proactive behavior show their great potential for using in supply chains and improving their performance.

In this model, we propose agent based supply chain. In improved model, intelligent agents establish integrated system that all echelons link to each other. In this way we try to establish agent managed supply chain with the central control and use central decision making in it.

6.1. Designing Multi Agent System

Multi agent system grew out of today's world need and a far-sighted view about the future's environmental conditions. On the one hand, the need for learner, self-organized and knowledge-oriented organizations, and on the other hand, the pressing need for decentralized problem-solving methods to control and plan complicated production systems and to predict the performance of social and economical complicated systems, has made the MAS the focus of attention [21]. Without coordination, a group of agents can quickly degenerate into a chaotic collection of individuals. These interdependencies need to be managed, which requires the building of coordination mechanisms to maintain a certain level of coherence between the different decision centers [11]. Multi agent system contains a number of agents, which interact with one another through communication.

The agents are able to act in an environment; different agents have different sphere of influence, in the sense that they will have control over different parts of the environment.

There are number of factors, which point to the appropriateness of methodologies for designing multi agent systems such as the environment (static and dynamic) and distribution of data. We used sooyang park methodology to design system [29]. They issue a paper that on it propose an architecture-based method for the systematic development of MAS. This methodology follows three main phases. The first phase in our approach is called ' problem analysis'. The main focus of this phase is in gaining an understanding of what the system does in the abstract, which serves as a starting point for the architecture development process.

After gaining an understanding of the domain and the overall goals of the system from the problem analysis, we move on to the next phase in which agents are identified to satisfy the analyzed goals and their relationship.

This phase is called ' Agent modeling'. In this phase, for each of identified agent, its internal behavior and belief are modeled. The final phase is 'MAS Architecturing' which focuses on the internal architecture of agents and setting up the federation of agents that collaborate with each other while maintaining autonomy to a large extent [19].

6.1.1. Problem Analysis

Problem analysis is essential for setting up system boundary and analyzing user requirements. There is an increasing trend towards designing agent-oriented software utilizing a goal-directed analysis process.

Goal-directed analysis mainly involves identifying higher-level goals, and for each of them generating sub goals and also defining the relationships between them. Goals are categorized into three types: system external goals, which are viewed from outside of the system; user goals, which are perceived by the users; and internal goals viewed from inside the system.

6.1.1.1. Goals of System

We define goals in three categories (external, user & internal goal). Fig.4 shows the results of problem analysis phase and goal diagram. These goals are determined based on illustrated model's structure,

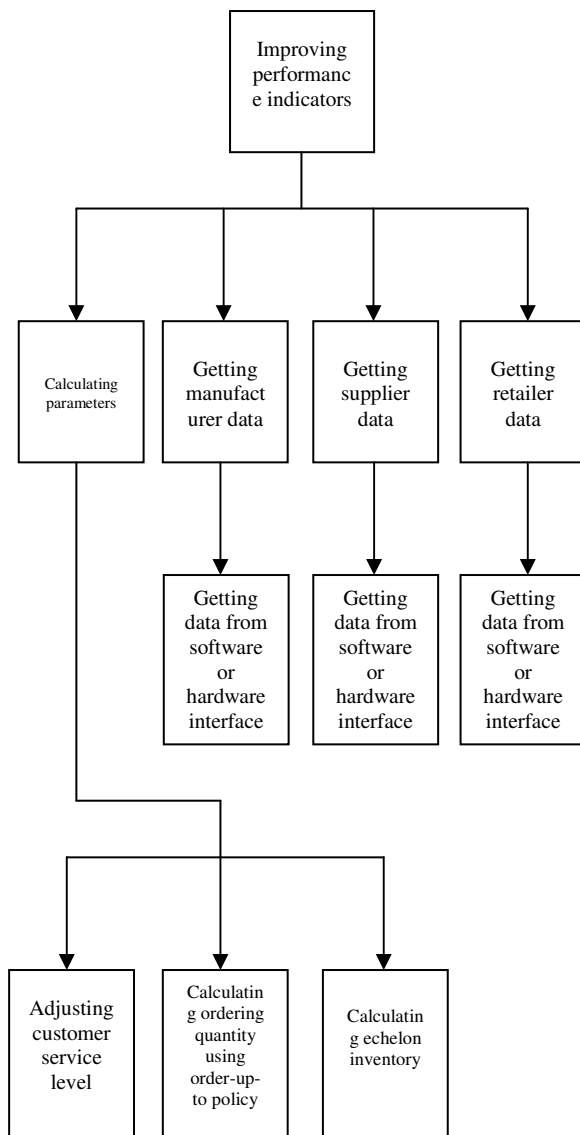objective of designing the new system such as make coordination and mentioned methodology in previous section.

Fig. 4. Goal diagram of agent-based supply chain

6.1.2 Agent Modeling
From the goal analysis, we identify agents for this domain. In this scenario 6 agents are needed;
RetailerInfo <<mobile agent>>
SupplierInfo <<mobile agent>>
ManufacturerInfo <<mobile agent>>
DB Wrapper <<agent>>
OrderQuantity <<agent>>
AdjustCSL <<agent>>
They are derived from internal goals of the goal diagram.

6.1.3. Multi Agent System Architecturing
After identifying appropriate agents for the system, in order to facilitate coordination among these agents, we define agent groups and coordinators for each of these groups that control the overall behavior of the system. In the previous section 6 agents have been identified for this problem domain, as well as two roles that are mapped to the following user groups: to get echelons data and calculating parameters. To manage these two roles of the system, two agent groups are formed and the coordinator for each group facilitates the interaction among agents in each group. Finally we present some details of how a multi agent system could be implemented using the proposed architecture-based approach.

At the end of each period RetailerInfo, SupplierInfo and ManufacturerInfo agents gather echelons inventory data. In initial model when echelons within a supply chain make forecast that are based on orders they receive, any variability in customer demand is magnified as orders move up the supply chain to manufacturer and supplier. In supply chains that exhibit the bullwhip effect, the fundamental means of communication between different stages are the orders that are placed. In reality, the only demand that the supply chain needs to satisfy is from the final customer.

If retailers share point-of-sale(POS) data with other supply chain stages, all supply chain stages can forecast future demand based on customer demand.

Designing a supply chain in which a single stage controls replenishment decisions for the entire supply chain can help diminish bullwhip effect. When a single stage controls replenishment decisions for the entire chain, the problem of multiple forecasts is eliminated [5].

In the agent-based model we try to use agents for sharing information and create centralized decision making to avoid mentioned problems. After getting echelons data, OrderQuantity agent calculates echelon safety inventory for each echelon. In this model, we define and use new term that is called echelon safety inventory. Echelon safety inventory for each stage of supply chain is all safety inventories between that stage and the lower stage:

$$SS(i) = SS(i) + SS(i-1)$$

That SS(i) represents safety stock of i'th level in supply chain. SS(1) represents safety stock of retailer, SS(2) represents safety stock of distributor and SS(3) represents safety stock of manufacturer. SS(0) represents inventory in the pipline coming to the retailer.

For knowing the cause of defining echelon safety inventory, consider a simple multi-echelon supply chain with a supplier feeding a retailer who sells to the final customer. The retailer needs to know demand, as well as supply uncertainty to set safety inventory level. Supply uncertainty, however, is influenced by the level of safety inventory the supplier choose to carry. If a

retailer order arrives when the supplier has enough inventory, the supply lead time will be short. In contrast, if the retailer order arrives when the supplier is out of stock, the replenishment lead time for the retailer will increase.

Thus, if the supplier increases its level of safety inventory, the retailer can reduce the safety inventory it holds. Thus, implies that the level of safety inventory at all stages in a multi-echelon supply chain should be related [5]. In the following AdjustingCsl agent, adjust customer satisfaction level based on order fulfillment rate. We separate environments condition into three categories:

(1) when order fulfillment rate is less than 0.7 (FR<0.7)
(2) when order fulfillment rate is between 0.7 & 0.8 (0.7<FR<0.8)
(3) when order fulfillment rate is between 0.8 & 0.85 (0.8<FR<0.85)

AdjustingCsl agent, does actions in each condition. If FR<0.7 then AdjustingCsl

agent adjusts customer satisfaction level in this way CSL:=CSL+0.05; if order fulfillment rate is between 0.7 to 0.8 then AdjustingCsl agent adjusts in this way CSL:=CSL+0.03 and if order fulfillment rate is between 0.8 and 0.85 then AdjustingCsl agent does this action CSL:=CSL+0.01. After these calculations, OrderQuantity agent calculate ordering quantity with order-up-to policy.

7. Experimental Results

In this section, the results of performance indicators of improved model are presented and then they will be compared with initial model. The total cost in the supply chain includes inventory holding cost and backorder cost for each echelon. In this paper, for the first echelon both of these costs are calculated, but for second and third echelon, only holding cost is calculated. In table 6, 7 costs of each echelon for initial and improved model are shown. As we see, in the initial model, when moving up in the supply chain, echelons costs are increasing and its cause is because of cumulating forecasting error in upper levels of supply chain and increasing inventory holding cost.

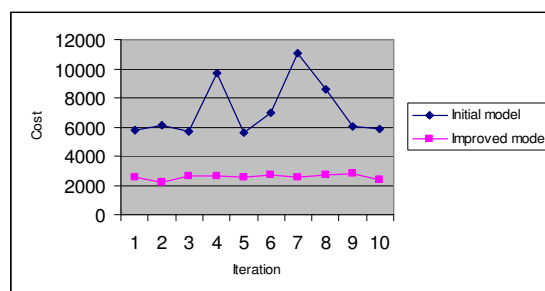**Tab. 6. Supply chain echelons cost in initial model**

Run	1	2	3	4	5	6	7	8	9	10
Ech1	4910	4477	5137	5404	5117	5718	6180	5498	6179	4978
Ech2	1411	729	1583	981	2011	978	200	1103	911	980
Ech3	1414	1429	1280	1529	1520	1520	1391	1527	1402	1314
Ave.	2578	2212	2667	2638	2739	2739	2590	2724	2830	2424

Tab. 7. Supply chain echelons cost in improved model

Run	1	2	3	4	5	6	7	8	9	10
Ech1	2911	3038	2520	2192	2737	2303	3735	3801	2826	2735
Ech2	5473	5834	5535	8420	5385	6007	9199	7905	5620	5537
Ech3	9068	9535	9046	18609	8622	12632	20138	13984	9581	9436
Ave.	5817	6136	5700	9741	5581	6981	11024	8563	6009	5903

In the improved model, this trend is contrast and its cause is existing central decision making and relationship between echelons in supply chain.

Fig. 5 shows the results in terms of total inventory levels costs.

Fig. 5. Supply chain echelons total costs in initial and improved models

During analysis of the bullwhip effect in the improved model, it can be found that relationship between echelons and defining echelons safety inventory leads to amplify bullwhip effect, because this relationship causes that variation in one echelons inventory level effects other echelons immediately and then amplify bullwhip effect.

Then this performance indicator in improved model is studied in two states. State one is when we have relationship between different echelons and state two is when this relationship is ignored.

In tables 8,9 bullwhip effect for initial and improved model, without the relationship between echelons are shown. Bullwhip effect average in initial model is 3.005 and in improved model is 1.9681.

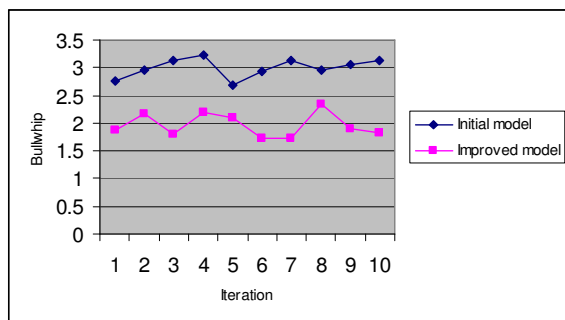**Tab. 8. Bullwhip effect measured in initial model**

Run	1	2	3	4	5	6	7	8	9	10
Bullwhip	2.77	2.95	3.14	3.24	2.69	2.93	3.14	2.96	3.06	3.12

Tab. 9. Bullwhip effect measured in improved model

Run	1	2	3	4	5	6	7	8	9	10
Bullwhip	1.88	2.16	1.80	2.19	2.09	1.72	1.72	2.35	1.91	1.82

Fig. 6 shows that bullwhip effect in improved model is in lower level and its cause is central decision making in improved model.

Fig. 6. Bullwhip effect measures in initial and improved model

A single point of replenishment decisions ensures visibility and common forecast that drives orders across the supply chain. Table 10 shows bullwhip effect in improved model with relationship between echelons. Average of this performance indicator in this condition is 6.22.

Tab. 10. Bullwhip effect measured in improved model

Run	1	2	3	4	5	6	7	8	9	10
Bullwhip	5.63	5.59	7.47	6.86	6.35	5.54	7.11	5.26	5.42	6.94

Tables 11,12 show order fulfillment rate in initial and improved model.

Tab. 11. Order fulfillment rate in initial model

Run	1	2	3	4	5	6	7	8	9	10
Bullwhip	0.9328	0.9325	0.9277	0.9373	0.9274	0.9378	0.9374	0.9323	0.9388	0.9358

Tab. 12. Order fulfillment rate in improved model

Run	1	2	3	4	5	6	7	8	9	10
Bullwhip	0.9347	0.9332	0.9217	0.9320	0.9269	0.9403	0.9280	0.9372	0.9327	0.9358

Hypothesis test to compare two data sets are done, p-value of this test is 0.54, then equality of two data sets averages is accepted. This study leads us to this fact that decreasing inventory level, echelons cost and bullwhip effect do not have effect on order fill rate and it does not show decreasing trend.

8. Conclusions

In this paper, new agent-based supply chain and agent-managed inventory methodology was proposed to improve its performance indicators. An initial model that composed of three echelon supply chain was analyzed and its performance indicators behavior studied with discrete event simulation. After that, we use sooyang Park methodology to design a multi agent system. With this methodology, problem was analyzed, required agents was identified and architecture of system was defined. New model was simulated and two models performance indicators have been compared with each other. Based on discrete event simulation, this approach shows improvement in the performance indicators of supply chain. The novel contributions of the paper are summarized as follows:

- Using MAS to coordination between different echelons and proposing ordering quantity for echelons based on final customer orders
- Creating relationship between inventory position of different echelons of supply chain
- Using agents reactive characteristics for responding to changes in supply chain
- Improving inventory position, bullwhip effect and total cost of supply chain

Agent-managed supply chain doesn't have most of VMI methodology obstacles, because in this methodology computer-based system to manage inventory is used that has autonomy and don't have human based systems weak points especially behavioral obstacles that in result of it each stage of the supply chain views its actions locally and is unable to see the impact of its actions on other stages, different stages of the supply chain blame each other for the fluctuations, no stage of the supply chain learns from its actions over time, because the most significant consequences of the actions any one stage takes occur elsewhere and lack of trust among supply chain partners.

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