31

Simulation Study on Dynamic Characteristics of VMI Supply Chain Inventory System Based on Multi-Agent System

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1. Introduction

Supply chain integrates supplier, manufacturer, wholesaler, retailer and end user to a system by logistics, business flow, information flow and cash flow. The enterprises in supply chain system are horizontally integrated and formed a strategic cooperative partnership. The supply chain inventory system is a sub-system of supply chain system. The purpose of inventory management of supply chain is to establish an effective method for controlling inventory by means of cooperation and coordination of various parties related to supply chain.

Design, control and effective operation of a system are based on our good grasp of the inherent law and characteristics of the system through the analysis and study of it. To analyze and study a system, first a model of the system should be set up, which is called modeling. The model is an abstract, intrinsic and simplified description of the real system. In a sense, the process of scientific research is the process of setting up a model of real world.

Usually, there are three approaches to the analysis and study of a system: analytic method, experimental (test) method, and modeling and simulation method. Analytic method needs to set up a mathematical model of the system, which means firstly equations of the system such as algebraic equation, ordinary differential equation, partial differential equation, difference equation or statistics equation are set up through identifying parameters of the system, and then analytical solutions are obtained by solving those equations. Analytic method is generally applicable to linear systems or some particular non-linear systems because it describes the behavior and characteristics of the system instead of real structure of the system. It is difficult to solve equations of complex non-linear system to obtain analytical solutions. Some systems are too complicated to set up their mathematical models. Therefore, the application of analytic method is limited.

Experimental method needs to set up an entity model (or physical model) of the system because it is hard to conduct experiment directly with real system. The adoption of experimental method is comparatively time-consuming with high cost, and the implement is impractical and sometimes even impossible.

Modeling and simulation method refers to a series of complex activities, such as setting up a model of real system and simulating on the computer. Modeling and simulation method is to simulate real system with a model. First a simulation model of real system is set up, then

simulations or experiments are conducted on computer to pre-perform or re-produce the operation process or operation rules of the system. Modeling and simulation method is of great flexibility, by which those systems that direct experiments are impossible to be made on could be simulated. It could save a lot of resources and expenses, greatly improve people's abilities to study and analyze complex systems so that it is a brand-new and effective method of systematic study and analysis and has become an important method of studying system behavior, evaluating various kinds of strategy and tactics, and diagnosing, analyzing and designing system.

It is mainly made up of three basic parts in the modeling and simulation system: real system, model and computer, among which modeling and simulation are two basic activities. Modeling is mainly concerned with the relationship between real system and model. By observing real system, an abstract, simplified, approximate model of real system is obtained, ignoring secondary factors and undetectable variables. In this process, the system is simplified according to the purpose of modeling and the essential characteristics of the real system. Hence in the modeling process it is important to single out and tackle the principal contradiction and the principal aspect of the contradiction. Model is the basis of simulation in that correct result of simulation could be got only when correct model and data are set up. Simulation mainly studies the relationship between model and computer, writes computer program and operates it on the computer according to model set up in the modeling process, and then analyzes the dynamic characteristics and operation rules of the system according to computation results.

Modeling and simulation method based on multi-agent system is a new type of computer modeling and simulation method appeared in 1990s and has been widely used in fields like physics, mechanical engineering, biology and social sciences.

Supply chain inventory system is a strong non-linear dynamic complex system. Its whole behavior mode results in the interaction among node enterprises which constitute the system. To study the dynamic characteristics of supply chain inventory system is to know well the operation rules of the system, with both individual and whole dynamic characteristics being the concerns. The main factors that influence the dynamic characteristics of supply chain inventory system are as follows: external demand, lead time, information, system structure and interactive operation mechanism inside of the system.

In this paper, the characteristics of multi-agent system and supply chain system are analyzed and compared, the dynamic characteristics of supply chain system is analyzed with a tool of modeling and simulation method based on multi-agent system, a multi-agent system model of multi-stage supply chain inventory system is sets up, and the dynamic characteristics of VMI supply chain inventory system is studied and analyzed by simulation on the Swarm Platform.

2. Multi-agent system

Agent technology was originated from the series studies on distributed artificial intelligence carried out by researchers in MIT in 1970s. At present, agent technology has been adopted in both the computer and non-computer fields. With the rapid development of agent theory and technology, it is increasingly difficult to give a strict and clear definition of the concept of agent which is universally accepted and is applicable in all fields. So far, there is no unified and exact definition of agent.

The basic idea of agent technology is to make software imitate social behavior and cognition of human beings, that is to say the organizational forms, cooperative relationship, evolutionary mechanism, the way of thinking and cognition, the way to solving problems as well. Compared with corresponding traditional Objective ideas, the concept of agent is more knowledgeable, proactive and cooperative, and is more powerful in solving problems, and is more autonomous.

Although different scholars give different concept and definition of agent, it is believed that agent has the intelligent property of imitating human beings. Its attributes are as follows:

1. Autonomy: Based on its belief, desire and intention (BDI), it can make autonomous decision and take proactive action according to its internal state and perceived environmental information, without control and operation from outside world. Besides, it has the ability to control its behavior and internal state. Autonomy is the embodiment of agent intelligence.
2. Proactive: It shows great initiative in taking proactive action towards intend goal according to internal state and external environment.
3. Reactivity: it can perceive the change of environment (including other agents) and make immediate response to the change.
4. Adaptability: It can gradually adapt itself to environment. It can learn and improve from experience to expand or amend its local knowledge.
5. Sociality: It can interact with other agents. It has interface and means to effectively connect with other agents and to form multi-agent groups to complete the task intended jointly through information exchange, collaboration, undertaking task, job sharing and cooperation, and distributed cooperative solving.
6. Persistence: It can keep operating at least in a rather long period of time.

Also, it has attributes such as honesty, compliance, sensibility, cooperativeness and mobility.

We call entities which possess all the above mentioned attributes or principal attributes as agent. Although there is no precise and unified definition of agent, we present the definition of agent in the light of the above analysis and discussion for the sake of convenience.

Definition of agent: Agent is defined as a certain abstract of a real system (it is generally an abstract of physical entity of the real system, but may be an abstract of the function of the real system as it is required), an entity possessing certain intelligence, which means it can acquire material and information to realize the goals for itself, draw inference and make decision, take proactive action, and interact with environment and other agents.

Multi-agent System is the forefront field in the distributed artificial intelligence (DAI). The idea of multi-agent system appears in Herbert A. Simon's work, Administrative Behavior (Simon, 1976). He argues in the book that a large system that organizes many individuals could make up for the deficiency due to individual's limited working capability. Similarly, the division of labor and each individual in charge of a special task could make up for the deficiency due to individual's limited capability of learning new task. The organized flow of information among administrative organizations could make up for the deficiency due to individual's limited capability of dealing with and making use of information to make decision. Although Simon's theory is in regard to human society, it lays a foundation for the basic idea of multi-agent system: the intelligence of individual agent is limited, but we could organize agents to form multi-agent system through proper systematic topology. In this

way, individual agent's deficiency is made up for and the capability of the whole system surpasses that of any individual agent.

Definition of Multi-agent System : Multi-agent system is defined as a system made up of many agents. It is a loosely-coupled network system of many agents formed to solve complex problems which are unsolvable by individual agent and go beyond the individual agent's capability and its scope of knowledge.

Each agent in multi-agent system could act on itself and environment, communicate with other agents, operate asynchronously, and interact with each other to finish tasks by collaboration and cooperation.

Modeling and simulation method based on multi-agent system is suitable for the study of distributed non-linear complex system with medium-scale. Medium-scale indicates that the number of agents that compose the system is neither too many nor too few. A system made up of very few agents is called simple system and could be studied by traditional mathematical methods.

A system with enough agents, for example gas in a container, could be studied by statistic methods. Distributed means the control of the system is distributive, and there is not a global control. The time control mechanism and the problem solving capability of the system and so on are also distributive. Non-linear refers to the interaction of components in the system. It does not conform to the principle of superposition, which means the whole does not equal the sum of the parts.

Compared with the traditional process oriented or object oriented simulation technology, modeling and simulation based on multi-agent system simplifies the modeling structure, reduces the complexity of modeling logic, enhances the capacity of intelligent behavior simulation, the capacity of concurent simulation, and the capacity of interactive and collaborative simulation. At the level of modeling and analysis, it is much more abstract and in particular applicable to modeling and simulation of systems with high complexity and inherent distributivity.

It must be pointed out that modeling and simulation technology based on multi-agent system is not a substitute for traditional technology (for example, nonlinear dynamics, system dynamics and game theory, etc.), instead it synthesizes and makes further improvement on the traditional research technology and techniques. Technically, modeling and simulation technology based on multi-agent system is an advanced technology in which agent is its key concept and multi-agent system its frame, and which is formed as a synthesis of traditional research technology (such as mathematical methods), advanced computer science and technology (such as computer network technology, distributed technology etc.), artificial intelligence (such as neural network, pattern recognition) and game theory. Compared with other traditional technology, it is more effective, more advanced and more promising.

In short, modeling method based on multi-agent system uses modeling thought and methodology that combine reductionism with holism. Its thought process is holistic thinkingreductive thinkingholistic thinking. It starts from holism's way of thinking, knowing well what to analyze in the system in a macroscopic way. Next it uses reductionism's way of thinking, resolving the system from the whole to individuals. Then it uses holism's way of thinking, assembling these individual elements according to the constituting mechanism. It combines individuals into a whole and comes to a comprehensive conclusion by analyzing evolution law of the system.

3. Characteristics of multi-agent system

"To operate in part while to share by the whole" (H. Wang, 2003) is at the very core of multi-agent system. The characteristics of multi-agent system are as follows:

1. Interactivity

Interactivity is the most important characteristic of multi-agent system which is the principal feature that distinguishes multi-agent system from other characteristics. Multi-agent system could describe complex group interaction mode and realize group interaction at a high lever, such as collaboration, coordination, cooperation, consultation and game playing etc.

Coordination means the agents with different goals reasonably arrange their goals, resources and so on to adjust their own behaviors to realize their own goals to the utmost. Coordination is required in multi-agent system.

Collaboration means many agents work together for their common goal.

Cooperation means that many agents cooperate to complete common goal by coordinating their own behaviors. It is a special type of coordination.

Consultation is that all the agents involved in interaction reach an agreement accepted by all.

Agents in multi-agent system intercoupled each other with rich relations, and interact in groups to form rich systematic structure. The relation and the structure evolve constantly with the interaction among the agents. The interaction of multi-agents could be carried out by information transmission. It could also be carried out at the level of knowledge by agent interaction communication language (such as Knowledge Query Manipulation Language (KQML), Agent Communication Language (ACL) etc.). The interaction of multi-agents is flexible and is required to be conducted by observing environment and other agents when the system is at work.

2. Dynamic characteristic

The structure of multi-agent system could either be static or dynamic. The structure, the interaction and interrelation among its members of static multi-agent system are stable and permanent. No change takes place when tasks or environment changes. It is a structure usually designed specifically for a certain goal or task. However, the structure, the interaction and interrelation among its members of dynamic multi-agent system are unstable and temporary. They change when tasks and environment change. The dynamic structure is formed usually as a result of competition among agents and system evolution. Dynamic multi-agent system is usually an unstable structure temporarily formed for a special task or goal. When the task or goal is completed, multi-agent system may be dissolved accordingly. New multi-agent system with different structure or members may be reformed for new task or goal.

The structure of multi-agent system could be either closed or open. Closed multi-agent system does not allow agent members to come in or go out freely. Its agent members are fixed. However, open multi-agent system allow agent members to come or go freely. Its agent members are not fixed but change dynamically.

3. Modularity

Multi-agent system is a system made up of a group of agents. Agent is an entity with higher autonomous capability, operated in dynamic environment. It is the basic element of multi-agent system and each agent could be seen as a module composing multi-agent system.

Agent combines in different ways may constitute different multi-agent system. Therefore, modularity makes multi-agent system more flexible, adaptable and reusable.

4. Complexity

The interaction of simple agent in multi-agent system could generate complex global (holistic) behavior of the system. This phenomenon is called "emergence" in complexity theory.

5. Isomerism

Agent members in multi-agent system could either be isomorphic or isomeric.

6. Distributivity

Knowledge, data and recourses in multi-agent system is discrete and the control is distributive. Each agent could control its own behavior on its own. Generally, there exists no global control.

7. Asynchronism

Calculation in multi-agent system is made asynchronously, each agent having its own behavior time table.

8. Hierarchy

The structure of multi-agent system is hierarchical in which agent at the superior hierarchy controls the agent's behavior at the subordinate hierarchy, while being controlled by agent at the higher hierarchy. The focal point of multi-agent system reserch is the cross-level study of the system.

The characteristics and behavior at the overall hierarchy of structure of the system are the emergence caused by interaction and constantly evolving among all component parts at the partial hierarchy in multi-agent system. The laws and phenomena of the superior hierarchy could be explained or infered from the laws of the subordinate hierarchy in multi-agent system, and it is believed that the subordinate hierarchy is more fundamental.

9. Incompleteness

Agent in multi-agent system is featured with incompleteness. There is no agent who knows what the all other agents are thinking or doing. It obtains information only from a comparatively small subset of the agent set, and the information acquired may also be incomplete. Each agent in the system interacts, makes decision and takes action by processing these bits of partial and incomplete information. As it owes only partial and incomplete information or knowledge, or capacity of solving part of problems, the range of vision of each agent is limited.

10. Variety of system evaluation index

The evaluation index of multi-agent system is various. We could use many different indices to evaluate the system, and every evaluation index gives description of system performance from a certain aspect. The performance evaluation of multi-agent system could be made at overall hierarchy or at individual hierarchy. It could be single index or comprehensive index. But none of them could make an overall evaluation of the system.

It could be seen from the above analysis of characteristics of multi-agent system that multi-agent system lays stress on distributed autonomous decision-making and cooperation among agents to solve problems. Multi-agent system is rich in relations and structures and could describe complex group interaction mode, therefore it is of great flexibility and adaptability. It is particularly fit for studies of problems in real world, in which complexity, coordination, self-organization, self-adaptation, formlessness and uncertainty are involved. It is very suitable for handling problems with distributed knowledge, data, resourses and

control. It shows human being's social intelligence to a greater degree, more suitable for the open, dynamic world environment. It is a method closer to problem-solving in natural world and could give a more natural account of the system, so that it has drawn more and more attention to this new and prosperous method of system modeling and simulation in academic circles.

4. Characteristics analysis of supply chain system

From the viewpoint of systematization, supply chain is a system made up of supplier, manufacturer, distributor, retailer and customers. Supply chain system includes four basic subsystems: logistics, information flow, capital flow and trade flow. Supply chain system exhibits the following characteristics in regard to its structure, operation and management:

1. Dynamic characteristic

Dynamic characteristic refers to time-varying characteristic of the system. In order to fit in with changes in market demands and business management strategy, the node enterprises in supply chain system should be updated and renewed often, so does the business management strategy and tactics of node enterprises, and the organization structure of supply chain is combinative, elastic, and dynamic. So that the supply chain system bears a clear dynamic characteristic.

The dynamic characteristic of supply chain system is divided into extrincic and intrinsic dynamic characteristics. The former implies that external environment as well as its related parameters change with time, such as external demand, policy, laws and regulations, and environment of supply chain. The latter is caused by the dynamic change inside of the supply chain system, and is subdivided into structural and operating dynamic characteristics. Structural dynamic characteristic means node enterprises of supply chain often needs to update and renew, and the organizational structure of supply chain is composable, elastic, and dynamic. Structural dynamic characteristic includes dynamic characteristic of members and of its members' interrelations in supply chain system.

The dynamic characteristic of system members means supply chain system allows its members to come in or go out of the system, that is to say the structure of the supply chain is open. It is shown mainly at the forming and breaking up stage of the supply chain system. At that time, stable structure of the supply chain does not yet formed.

The dynamic characteristic of its members' interrelations in supply chain system means although there is no change in members of the supply chain system, the interaction and interrelation among these members change. It is usually shown in the operation process of mature supply chain system. At that time, stable or lasting strategic cooperative partnership has been formed among member enterprises of the supply chain, and the interaction among system members needs to adjust to improve the operation efficiency of the system.

Operating dynamic characteristics means supply chain members often renew and readjust the management tactics and strategy of the enterprises to meet the enterprise tactics and market demands. It is mainly realized by dynamic renewal of operation parameters of the system.

Both the extrincic and intrinsic dynamic characteristics of supply chain system could cause dynamic change of the system. In real supply chain system, these two characteristics are usually interwoven to produce effects on the operation of the supply chain system.

2. Integrity

Supply chain system composites all the node enterprises in the supply chain as a whole. The extent of supply chain management is exercised in the whole chain, involving supplier,

manufacturer, distributor, wholesaler and end user, covering the scope of purchase, production, inventory, distribution and sales. The supply chain management strives to make the whole process of supplier, manufacturer, wholesaler, retailer till end user be wholly in optimum state.

3. Crossing

Node enterprises could be a member of this supply chain but at the same time a member of another supply chain. A great number of supply chains forms a crossed structure, increasing the difficulty in coordination of supply chain management.

4. Interaction

In supply chain system, node enterprises interact in groups with each other by way of collaboration, coordination, cooperation, consultation and game playing.

5. Cooperation

In supply chain, the relation between any two nodes is all supply and demand. The relation among node enterprises in supply chain is a kind of long-term and open strategic cooperative partnership, not a life-and-death competition. From the viewpoint of game theory, the relation between node enterprises of supply chain is not zero-sum game.

6. Complexity

As the span of supply chain and the hierarchy of node enterprises constituting supply chain are different, supply chain is usually constituted by a lot of and a wide range of enterprises, and even transnational enterprises, so that the structural pattern of supply chain is more complex than that of one enterprise. Supply chain management involves complex interaction among node enterprises that leads to its holistic performance. Complex holistic behavior mode of system emerges by interaction of node enterprises in supply chain. This is the complexity of system.

7. Agility

Time is money. Supply chain management is a time priority competitive strategy which can shorten the time of delivery, rapid response to market demand.

8. Integration

System integration means two or more elements (unit, subset) combine into an organic whole. Integration is a concept of constructing system and also a synthetic way to solve complex system problems and improve the holistic function of system. Integration is not the simple superposition of elements, but the organic combination of them. In other words, the combination and construction of elements is based on a certain integrated rules to improve the integrated function of the system. Supply chain management uses the idea and method of integration to combine product development, production, inventory, distribution and sales of supply chain, making use of the advanced theory and technology, such as Concurrent Engineering (CE), Just In Time (JIT), Electronic Data Interchange (EDI), Electronic Ordering System (EOS), Database, Bar Code, Customer Relationship Management (CRM), Efficient Consumer Response (ECR), Quick Response (QR), Business Process Reengineering (BPR), Material Requirements Planning (MRP), Manufacturing Resource Planning (MRP II), Enterprise Resource Planning (ERP), Flexible Manufacturing System (FMS), Computer-Integrated Manufacturing System (CIMS). It accomplishes not only the simple connection of resources like node enterprises, technology but seamless connection.

9. Multi-objective

The goal of supply chain management contains efficiency and effectiveness. The multi-objective of supply chain diversifies the evaluation indices of supply chain performance.

The index could be single index or comprehensive index, local index or global index. But no matter whether it is, single index or comprehensive index, local index or global index, evaluation indexes of supply chain system could not make an overall evaluation of system. Supply chain management tries to achieve balance among multi-objective.

10. Hierarchy

Hierarchy of supply chain system consists of the hierarchy of structure and the hierarchy of management. The structure of supply chain system is hierarchical, and the behavior mode of system presented in the whole hierarchy is produced by the interaction of node enterprises in supply chain system. Because of the structural hierarchy of supply chain system, a cross-hierarchy study on supply chain system is requested.

Supply chain management is divided into three levels: strategic plan of supply chain (strategy level), management control of supply chain (tactics level) and operation managementof supply chain (operation level). Strategic plan of supply chain is concerned with decision-making of the design of the whole supply chain. Decision-making at this level is a long-term decision-making and determines the structure of supply chain and the process which all the links in the chain must go through. It is a managing behavior of highest ranking and is completed by the core enterprise. It includes decision-making such as selection of factory location, selection of supplier, selection of means of transportation, choice of information system, determination of means of information transmission, analysis of product demand and choice of product and so on.

Management control of supply chain is the secondary hierarchy of supply chain management with more details than the first hierarchy. At this level, structure of supply chain is determined, and management control decision-making is mainly made at company level for the purpose of increasing the efficiency and effectiveness of the enterprise. It includes decision-making such as purchase, manufacturing, inventory, distribution and sales.

The third hierarchy of supply chain management is operation management including decision-making such as order processing, shop scheduling, vehicle dispatching, package and so on.

11. Stage characteristic

From the perspective of life cycle, supply chain could be divided into forming stage steadily operating stage and breaking up stage.

12. Modularity

Supply chain is set up above the level of enterprise, formed by the interaction among enterprises. Node enterprise is the basic operating unit in supply chain and each node enterprise has its independent decision, independent operation and independent accounting, and enjoys a strong independence in supply chain system, so that each node enterprise in supply chain could be regarded as an independent module in supply chain system. Enterprises combine in different way will form different supply chain. Modularity makes the study of supply chain system simplified in that researchers' only concern is the external characteristics of each node enterprise in supply chain, not the internal structure and operation of the module, and the stress is placed on the interaction among enterprises.

13. Distribution

The knowledge, data and resources of supply chain system are all distributive. The control of supply chain system is also distributive. There is no global control of supply chain system.

14. Adaptability

Each node enterprise in supply chain system is proactive in adapting to environmental change, so that the supply chain system as a whole has also the ability to adapt to environmental change, therefore bears the adaptable characteristic.

15. Concurrency

Each node enterprise in supply chain could operate in accordance with its own behavior time-table and could accomplish concurrent operation apart from necessary interaction operation.

By comparing the above mentioned characteristics of supply chain system with that of multi-agent system, we could conclude that the main characteristics of supply chain system amazingly coincide with that of multi-agent system, so that modeling and simulation method based on multi-agent system is the best tool for the study of dynamic characteristics of supply chain inventory system.

5. Multi-agent system model of VMI supply chain inventory system

Structure and operation mode of system is the key factor that affects the performance of supply chain inventory system. VMI supply chain inventory management strategy breaks traditional division inventory management mode, manages inventory in a systematic and integrated way, by which supply chain inventory system operates synchronically and is quick to adapt to market change. It is a new and representative supply chain inventory management mode and a new effective inventory management method under Supply chain environment.

VMI is a cooperative strategy between superior and subordinate nodes of supply chain which optimizes the availability of products with the cost lowest to the two parties, and with a target framework accepted by mutual parties, the inventory management of subordinate node is exercised by superior node. The target framework like this is constantly supervised and revised to produce an continuous improving environment.

The characteristics of VMI supply chain inventory management mode are as follows,

1. VMI is a cooperative strategy between superior and subordinate nodes of supply chain. When this strategy is implemented, superior and subordinate nodes in supply chain cooperate and trust each other, the information of inventory state is transparent and open to the two parties, and the benefit is shared by both supply and demand parties. The openness of inventory state is key to implementing VMI in that superior node could keep an eye on and check the inventory state of subordinate node at any time, make quick response to the change of market demand and make corresponding adjustments to the state of production and supply of enterprise.
2. The target of VMI is to make the lowest total cost of inventory system. VMI is not concerned with how cost is distributed or by whom it is paid, but the reduction of cost. By implementing VMI, the costs of both supply and demand parties are lowered and the costs of the whole supply chain inventory system are lowered accordingly.
3. VMI is a proxy model of decision-making for supply chain integration operation. In essence, it authorizes superior node to make decision for subordinate node inventory in supply chain. The superior node draws up inventory allowed by subordinate node, decides on inventory level and replenishment strategy, and holds the control of inventory. To delegate inventory decision-making of subordinate node to superior node reduces the levels of management decision-making in supply chain inventory system.

4. Superior and subordinate nodes in VMI must reach a target framework agreement on inventory management. In the target framework agreement, the common target of VMI, duties of superior and subordinate nodes etc. should be agreed on. It should also make clear where to place inventory, when to pay, whether to pay management fee or not, how much it will cost etc.
5. VMI adopts Continuous Replenishment Program (CRP). Traditional means of ordering is that subordinate node enterprises offer orders to superior node enterprises. However, as to VMI, it is superior node enterprises that decide on the replenishment amount of goods according to inventory and sales information of subordinate node enterprises. It is a powerful means to implement VMI inventory management strategy.

In order to make a quick response to subordinate node enterprises' requirement of reducing inventory, superior node enterprises, by establishing cooperative partnership with subordinate node enterprises, proactively heighten the frequency of delivery to subordinate node enterprises. In doing so, superior node enterprises turn out to be responsible for replenishing inventory for subordinate node enterprises, instead of only acting on purchase orderings of subordinate node enterprises. While superior node enterprises quicken their responses to its customers' needs, the inventory level of subordinate node enterprises is also lowered.

A typical topology structure of VMI supply chain inventory system is shown in Fig. 1.

In order to set up multi-agent system model of VMI Supply Chain Inventory System, node enterprises of VMI supply chain inventory system are simplified as agents. The model of multi-agent system model of VMI supply chain inventory system shown in Fig.1 consists of four agents, namely, retailer agent A_1, Wholesaler agent A_2, distributor agent A_3 and manufacturer agent A_4.

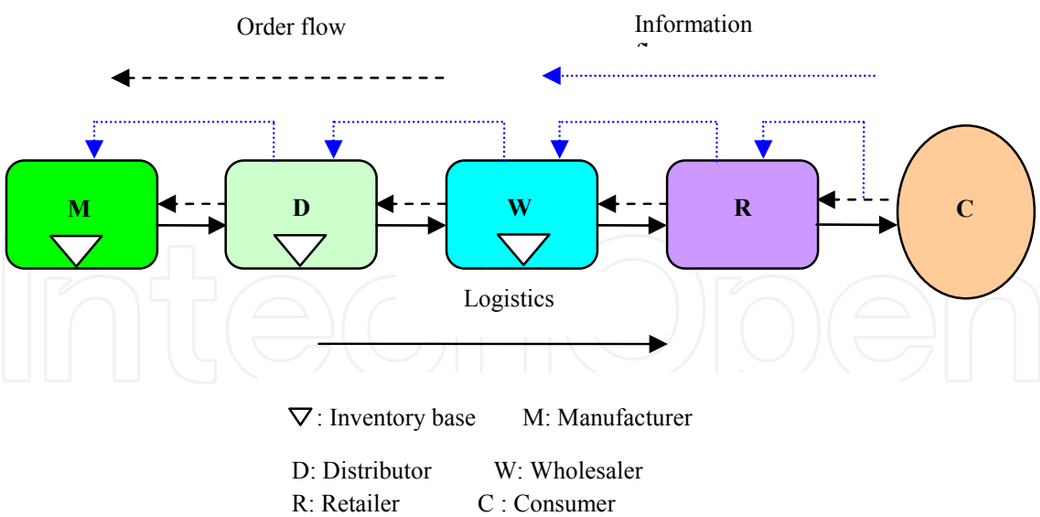

Fig. 1. Topology structure of VMI supply chain inventory system

The model of each agent $A_i(i=1,2,3,4)$ in multi-agent system model can be expressed with the following six tuple set:

$$A_i = \langle T_i, S_i, B_i, R_i, P_i, N_E \rangle \tag{1}$$

In the above expression, T_i is the partial time base of $A_i(i=1,2,3,4)$. Each agent A_i has its own partial time base which can be used to control the partial process of agent. The supply chain inventory system is operated periodically. Therefore it is a discrete time system and the partial time base is a set of integer. S_i is the internal state set. Each agent A_i in the model of multi-agent system has its own internal state set. In the multi-agent system model of supply chain inventory system, S_i includes the actual inventory, backorder, effective inventory and inventory cost etc. The variation of state is determined by state set and behavior set. B_i is behavior set. In the operation process of supply chain inventory system, the behavior set B_i of node enterprise agent includes demand forecasting, confirming quantities of order, making an order, making a delivery, renewing the record of state, etc. R_i is familiar relationship set. $FR=\bigcup_{i=1}^{n} R_i$. P_i is attribute set. Attribute set P_i represents the unique and indispensable quality of agent. N_e is external environment.

It is the most important to establish the decision-making model for each node enterprise agent in setting up the multi-agent system model of supply chain inventory system. In the practical operating process of VMI supply chain inventory system, decision-making is done by each node agent independently. Each node agent makes decision according to its preference, policy of decision-making and information obtained. For simplicity, it is assumed that each agent is isomorphic.

Information sharing is implemented in VMI supply chain inventory system. The Information sharing agreements are reached between the adjacent node enterprise agents. The real variations of requirement are passed on from the downstream node enterprise agent to the adjacent upstream node enterprise agent. One decision making levels are decreased in VMI compared with normal multi-echelon supply chain inventory management system. The decision-making policies of all agents in the model are described as (2)-(12).

$$\forall i, IO_t^i = \hat{L}_t^i + AS_t^i + ASL_t^i \tag{2}$$

$$\forall i, O_t^i = Max(0, IO_t^i) \tag{3}$$

$$\forall i, \hat{L}_t^i = \Theta^i L_{t-1}^1 + (1-\Theta^i)\hat{L}_{t-1}^1 \quad 0 \le \Theta^i \le 1, \ i=2,3,4 \tag{4}$$

$$\forall i, AS_t^i = \alpha_s^i (S_t^{i^*} - S_t^i) \tag{5}$$

$$\forall i, S_t^{i^*} = \delta^i \hat{L}_t^i \tag{6}$$

$$\forall i, ASL_t^i = \alpha_{sl}^i (SL_t^{i^*} - SL_t^i) \tag{7}$$

$$\forall i, SL_t^{i^*} = \gamma_t^i \hat{L}_t^i \tag{8}$$

$$\forall i, I_t^i = I_{t-1}^i + Min(I^{i+1}_{t-LT^i}, O^i_{t-LT^i}) - O_t^{i-1} \tag{9}$$

$$\forall i, C_t^i = h^i Max(0, I_t^i) + p^i Max(0, -I_t^i) \tag{10}$$

$$C_t = \sum_{i=1}^{n} C_t^i \tag{11}$$

$$C = \sum_{t=1}^{N} C_t = \sum_{t=1}^{N} \sum_{i=1}^{n} C_t^i \tag{12}$$

Where:

i : the sequence number of node enterprise Agent.

IO_t^i : nominal orders of the ith node enterprise in period t.

$\hat{L}_t^i$: forecasting demand of the ith node enterprise in period t.

AS_t^i : adjustment parameter of inventory level of the ith node enterprise.

ASL_t^i : adjustment parameter of inventory in transit of the ith node enterprise.

O_t^i : actual orders of the ith node enterprise in period t.

L_{t-1}^1 : actual demand of the *1*th node enterprise in period *t-1*.

$\hat{L}_{t-1}^1$: forecasting demand of the *1*th node enterprise in period *t-1*.

Θ^i :forecasting coefficient of update rate of the ith node enterprise.

S_t^{i*} : expected level of inventory of the ith node enterprise in period t.

S_t^i : actual level of inventory of the ith node enterprise in period t.

α_s^i : adjustment coefficient of the inventory level of the ith node enterprise.

δ^i : adjustment coefficient of the expected level of inventory for the ith node enterprise.

SL_t^{i*} : expected level of inventory in transit for the ith node enterprise in period t.

SL_t^i :actual level of inventory in transit for the ith node enterprise in period t.

α_{sl}^i : adjustment coefficient to the expected level of inventory in transit for the ith node enterprise.

γ_t^i : ordering lead time for the ith node enterprise.

I_t^i : actual inventory of the ith node enterprise.

C_t^i : inventory cost of the ith node enterprise in the period t.

h^i : holding cost of inventory per unit per week for the ith node enterprise.

p^i : shortage cost per unit per week for the ith node enterprise.

C_t : inventory cost of the whole supply chain in the period t.

C : total cost of the whole supply chain.

N: number of period for simulation.

n: total numbers of node enterprises in supply chain.

LT^i : lead time of the ith node enterprise.

6. Simulation and analysis of VMI supply chain inventory system

Simulation is conducted to VMI supply chain inventory system on Swarm Platform. Simulation parameters are as follows:

Initial conditions: The initial value of inventory in all node enterprises is 12 units. The orders of each node and inventory in transit are both 4 units per week.

System parameters: The **s**ystem parameters are as follows:

Θ^i =0.25, δ^i =3, α_s^i =0.6, α_{sl}^i =0.5, LT^i =1, h^i =0.5 yuan/unit/week, p^i =2.0 Yuan/unit/week.

External demands: The external demand orders of customers remain 4 units per week.

The simulation results are shown in Fig. 2-Fig.5.

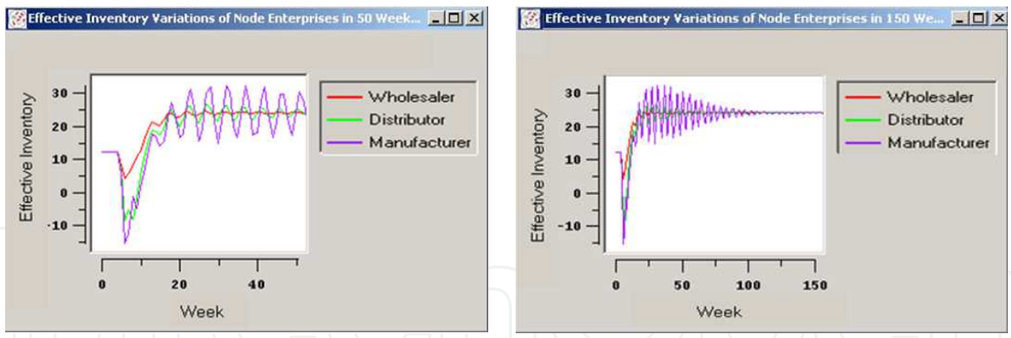

Fig. 2. Effective inventory variations of node enterprises in 50 weeks and in 150 weeks

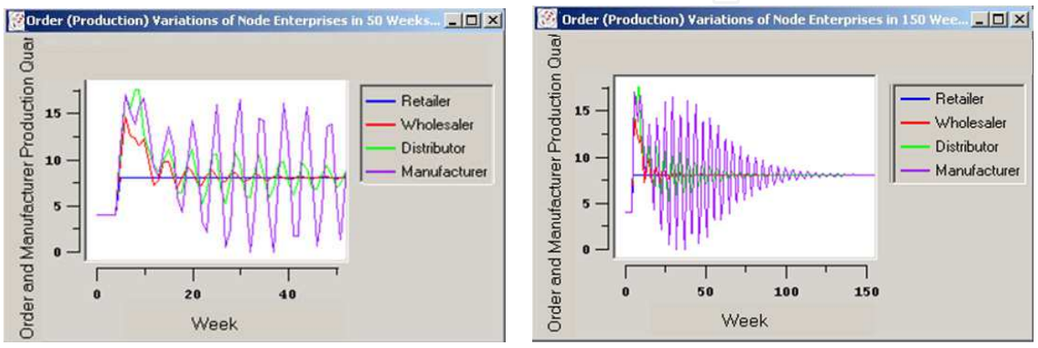

Fig. 3. Order (production) variations of node enterprises in 50 weeks and in 150 weeks

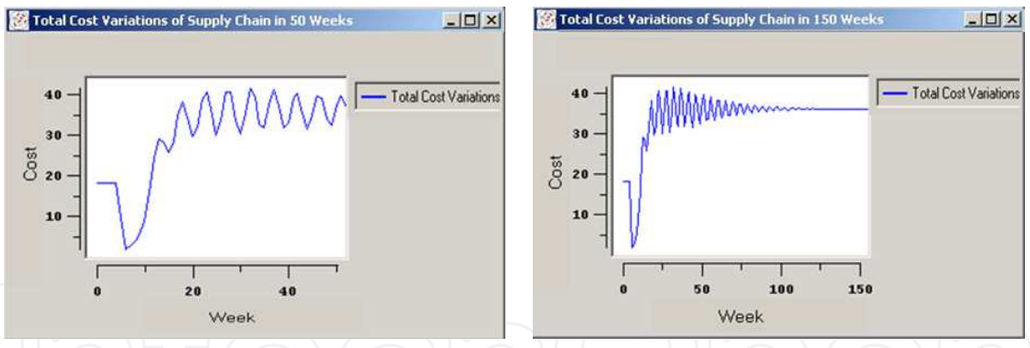

Fig. 4. Total cost variations of supply chain in 50 weeks and in 150 weeks

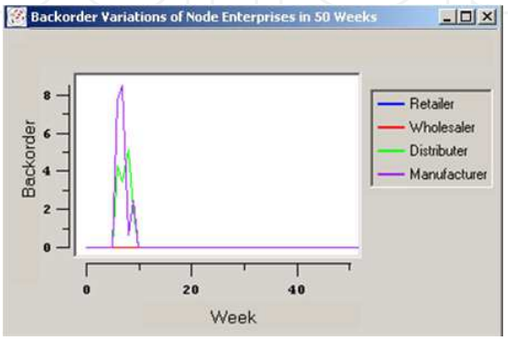

Fig. 5. Backorder variations of node enterprises in 50 weeks

7. Conclusion

By comparing the characteristics of multi-agent system with that of supply chain system, it is concluded that the main characteristics of supply chain system amazingly coincide with that of multi-agent system, so that modelling and simulation method based on multi-agent system is the best tool for the study of dynamic characteristics of supply chain inventory system.

It is concluded that the variation amplitudes of effective inventory of each node enterprise in supply chain shall decrease more effectively by adopting the VMI supply chain inventory management strategy (Fig. 2.), by comparing the above simulation results with (J. Li et al., 2007) and(J. Wang et al.,2005), especially for the upstream node enterprises. The responses of upstream and downstream enterprises to the variation of external demands are synchronous. The response delaying phenomena of effective inventory of upstream node enterprises are mitigated.

The orders to upstream node enterprise decrease obviously. The orders of the upstream node enterprise decrease more evidently than that of the downstream node enterprise. The variations of orders of each node enterprise are synchronous. The Bullwhip Effect of the whole supply chain alleviates greatly, but it does not disappear.

The backorders decrease apparently and sharply. There are no backorders in retailer and wholesaler. That means the serve levels are not lowered. The operation states of the whole supply chain are improved.

The whole costs of the supply chain are lowered obviously. The time from oscillation states to stable states of supply chain inventory, order and the whole costs are shortened, which is caused by the pulse variation of external demand.

From the analysis above, it is obvious that VMI is an effective inventory management method. The performance of supply chain inventory system can be enhanced effectively by adopting VMI strategy. The whole operation costs of supply chain can also be lowered greatly.

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Over the past few decades the rapid spread of information and knowledge, the increasing expectations of customers and stakeholders, intensified competition, and searching for superior performance and low costs at the same time have made supply chain a critical management area. Since supply chain is the network of organizations that are involved in moving materials, documents and information through on their journey from initial suppliers to final customers, it encompasses a number of key flows: physical flow of materials, flows of information, and tangible and intangible resources which enable supply chain members to operate effectively. This book gives an up-to-date view of supply chain, emphasizing current trends and developments in the area of supply chain management.

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