Study on Operating Mechanisms and Dynamics Behavior of Agile Supply Chain

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***Abstract* —To study deeply the operating mechanisms and system underlying behavior of agile supply chains, a new method—systems dynamics (SD) is introduced into the analysis of agile supply chain's behaviors.According to the characteristics of agile supply chain, its operating mechanisms was analysed and the dynamics model of it was established .Then the simulation analysis of systemic behavior of agile supply chain was conducted under the circumstances of disturbance of market. At the same time, the simulation of ordering cycle and target inventory's influence to the behavior of agile supply chain was run. The results indicate that: for agile supply chain, the delivery ratio of it can be increased not only through adjusting order cycle time, but also through changing target inventory, which all can increase delivery ratio of the whole supply chain.**

***Index Terms*—agile supply chain, operating mechanisms, dynamics behavior characteristics, simulation**

I. INTRODUCTION

Agile supply chain is defined as the dynamic network of supply and demand, which composed of a number of supply-side and demand-side entities can do the rapid response to environmental changes, demand-side entities in the competitive， cooperative and dynamic market environment [1-3]. Agile supply chain emphasizes the importance of supply chain's rapid response capability to market change and customer demand. It requires large enterprise groups, complex production process, even specific products, each employee to have agility, which is distinctly different from lean supply chain [4].

Nowadays, the study on behavior characteristics of agile supply chain is by the method of qualitative and static analysis. However, supply chain is a dynamic and balanceable system. The static analysis method can not show the whole supply chain's operational discipline, and the qualitative method can only obtain some perceptual knowledge, not achieve quantitative acquaintance. System dynamics provides a qualitative and quantitative, semi-quantitative analysis of the problem. It characterized as a precursor to quantitative support [5]. Since Forrester published "industrial dynamics" in 1961, the system dynamics method has been applied in a variety of industrial policy-making and strategic issues [6,7]. Although the system dynamics model of supply chain constructed by Forrester is called in question in a very long time .since system dynamics in the early 20th century was introduced to China, thousands of people , including Wang Qifan [8,9], Su MaoKang [10], Hu Yukui [11] and other scholars, involved in the application of system dynamics research work in China,but in the field of supply chain management, the literature about applied research is relatively rare.

As time goes by, the role in supply chain management research using system dynamics is increasingly recognized [12], and its application recently is more widely. The application of system dynamics method to study supply chain's issues is hot recently. Now research about supply chain is related inventory [13,14], retailer's behavior [13], logistics financial balance [15], the stability of supply chain [16] as well as the ability to re-plan [17] etc. The paper [13] established a new model of supply chain by exploiting computer simulation software provided by system dynamics to simulate ordering behavior of retailers. An analysis was made on the various changing indexes under two strategies: (1) ordering amount in terms of sale amount and(2) ordering amount in terms of sale amount and inventory. The paper [14] focuses on the analysis of simulated impact of the radio frequency identification (RFID) system on thenventory replenishment of the thin film transistor liquid crystal display (TFT-LCD) supply chain in Taiwan. A global operations and logistics case of a well-known LCD monitor manufacturer in Taiwan has been studied. The pull-base dulti-agents supply chain was accordingly modeled and simulated with AnyLogic. An automatic inventory replenishment unction adopting the (s,S) policyis enabled with RFID or not. The studies of paper [15] were made on keeping the balance of supply-demand of funds in the supply chain system based on system dynamic theory. System dynamic logic model and

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mathematical equations showed that when the logistic system experienced perturbation, a supply-demand balance could be achieved by the self-organization of the logistic system; when the perturbation accumulated into macro fluctuation, balance could be achieved by macro evolution of the system self-organization. The paper [16] proposed a system-dynamics-based criterion for stability judgment. With simulation, the criterion could be used to describe the nonlinearities of supply chain system with 1st order exponential lag and Pure Time Delay (PTD). The criterion could be used to judge the influences exerted on supply chain stability by decision behavior.The paper [17] analyzed the behavior of the generic system under study through a simulation model based on the principles of the system dynamics methodology. The simulation model provides an experimental tool, which can be used to evaluate alternative long-term capacity planning policies("what-if" analysis) using total supply chain profit as measure of policy effectiveness.In all these papers no document studies behavior of agile supply chain. So, through the simulation of agile supply chain on different conditions, some important characteristics can be obtained, which can supply the reference for supply chain operation.

II. The OPERATING MECHANISMS AND DYNAMICS MODEL OF AGILE SUPPLY CHAIN OPERATION

Agile supply chain runs in the form of market demand-pull from the downstream supply chain close to market customers to the upstream supply chain close to supplier. Agile supply chain can be understood as the mode that the enterprises in the downstream supply chain send order message to the upstream enterprises according to demand conditions on necessary time, and the upstream enterprises organize production according to product storage to meet the needs of the upstream enterprises.In this paper, related study is conducted on the basis of taking three-tier supply chain (which includes supplier, manufacturer and distributor) as object. the operating mechanisms and dynamics Model of agile supply chain can be seen from Fig.1.

In Fig. 1 the relation among these variables is:

average demand=SMOOTH(market demand, smooth time);

order 2= supplier's target inventory － supplier's inventory; order ratio 1= order 1/ supplier's order cycle time;

supplier's production= order ratio 1－reject ratio 1－inspection ratio 1;

inspection ratio1=supplier's production*percent of pass 1/inspection time 1;

reject ratio 1=supplier's production*(1 － percent of pass 1)/inspection time 1;

supplier's inventory=inspection ratio 1－output ratio 1;

output ratio 1=order ratio 2;

delivery ratio 1=IF THEN ELSE(supplier's inventory < output ratio 1 － inspection ratio 1:AND: supplier's inventory + inspection ratio 1>0, (supplier's inventory + inspection ratio 1)/ output ratio 1 ;

delivery ratio 1=IF THEN ELSE(supplier's inventory + inspection ratio 1<0, 0 , 1));

order ratio 2=order 2/ manufacturer's order cycle time; order 2= manufacturer's target inventory－manufacturer's inventory;

manufacturer's production=output ratio 1－reject ratio 2－inspection ratio 2;

reject ratio 2=manufacturer's production*(1－percent of pass 2)/inspection time 2;

inspection ratio 2=manufacturer's production*percent of pass 2/inspection time 2;

manufacturer's inventory=inspection ratio2 － output ratio 2, output ratio 2=order ratio 3;

delivery ratio 2= IF THEN ELSE(manufacturer's inventory < output ratio 2－inspection ratio 2:AND: manufacturer's inventory + inspection ratio 2>0, (manufacturer's inventory + inspection ratio 2)/ output ratio 2 , IF THEN ELSE(manufacturer's inventory + inspection ratio2<0, 0 , 1));

order ratio 3=order 3/ditributor's order cycle time; ditributor's production=order ratio 3－reject ratio 3－inspection ratio3;

inspection ratio3= ditributor's production*percent of pass 3/inspection time 3;

reject ratio3= ditributor's production*(1－percent of pass 3)/ inspection time 3;

ditributor's inventory=inspection ratio3－sales rate 3, delivery ratio 3=IF THEN ELSE(ditributor's inventory<sales rate 3 － inspection ratio 3:AND: ditributor's inventory+inspection ratio 3>0, (ditributor's inventory＋inspection ratio 3)/sales rate 3 , IF THEN ELSE(ditributor's inventory<0, 0 , 1));

sales rate 3= average demand;

$$delivery\ \ ratio\ \ i=\begin{cases} inventory \Big/ inspection\ \ ratio\ \ i & \text{condition ①} \\ 0 & \text{condition ②} \\ 1 & \text{condition ③} \end{cases}$$

Condition ①:

$$0 \prec inventory + inspection\ \ ratio\ \ i \prec out\ \ ratio\ \ i$$

Condition ②:

$$inventory + inspection\ \ ratio\ \ i \le 0$$

Condition ③:

$$inventory + inspection\ \ ratio\ \ i \succ out\ \ ratio\ \ i$$

In which i=1,2,3.

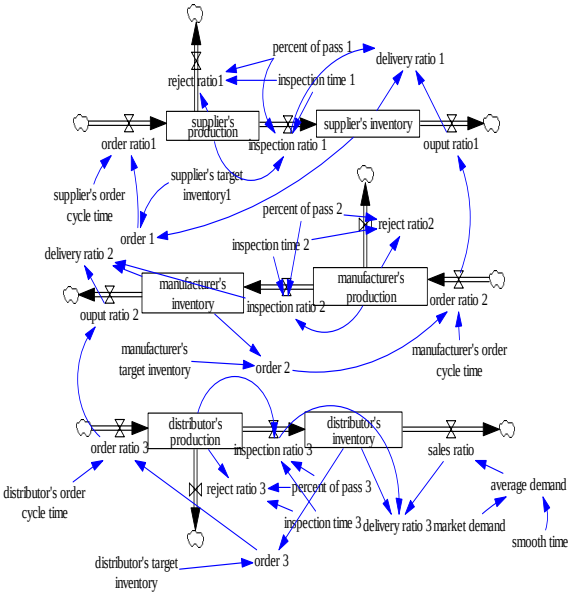


Figure 1. Operating mechanisms and Dynamics Model of agile supply chain

III. SIMULATION ANALYSIS

Simulation software used in this paper is vensim. vensim is a software developed and used in recent years, which can assist to complete the system modeling and flow-chart drawing and can further present the simulation results [11,18].

A. Systemic Behavior Under The Circumstance Of Market Disturbance

Suppose market demand obeys normal distribution function RANDOM NORMAL (0 ,10 , 5 , 5 , 0).

Other state variables' initial values are set as follows:

supplier's order cycle time= manufacturer's order cycle time = ditributor's order cycle time=2;

inspection time 1= inspection time 2=inspection time 3=smooth time=2;

percent of pass 1= percent of pass 2= percent of pass 3=0.95;

supplier's target inventory= manufacturer's target inventory= ditributor's target inventory=20;

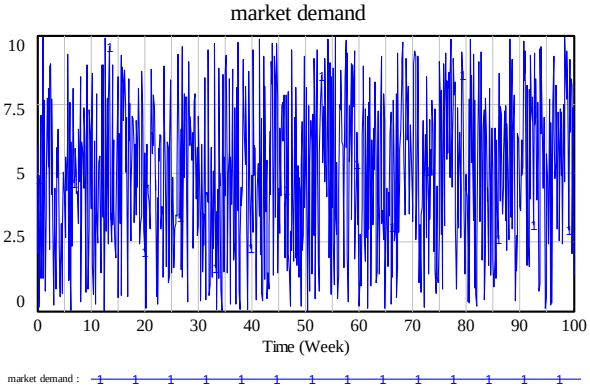
Time step of simulation =0.125;

Initial time=0,Final time=100;

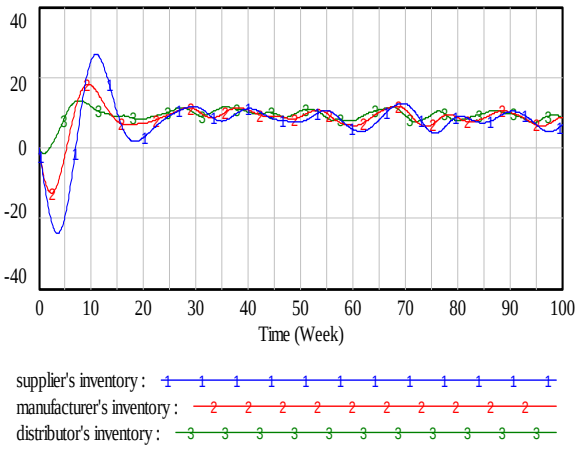
Fig. 2 shows the changes of simulation, including supplier's inventory, manufacturer's inventory, distributor's inventory and delivery ratio 1, delivery ratio 2, delivery ratio 3 before market demand's disturbance.

Now, add a disturbing function to market demand, then the distribution function of market demand is RANDOM NORMAL (0,10,5,5,0) +PULSE(50,100)*5. Systemic behavior changes can be seen from Fig. 3 after market demand's disturbance.

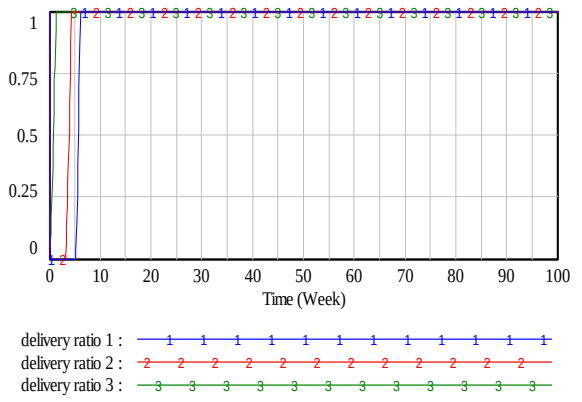
From the change between Fig. 2 and Fig. 3, we can see the curves of supplier's inventory ,manufacturer's inventory and distributor's inventory shift down to horizontal axis after market demand 's disturbance and fluctuates slightly , which explains that for agile supply chain their delivery is still stable when market demand is stable or not ,but market demand's disturbance has influence to supplier's inventory, manufacturer's inventory and distributor's inventory and their devery ratio. From table I, we can see clearly that with market demand's increasing suddenly the values of delivery ratio 1 and delivery ratio 2 reduces relatively large, but the value of delivery ratio 3 changes from 0.9930 to 0.9164, reducing relatively small, which shows that market demand 's disturbance has a smaller effect on delivery ratio 3 than delivery ratio 1 and delivery ratio 2.



（a）Market demand obey normal distribution

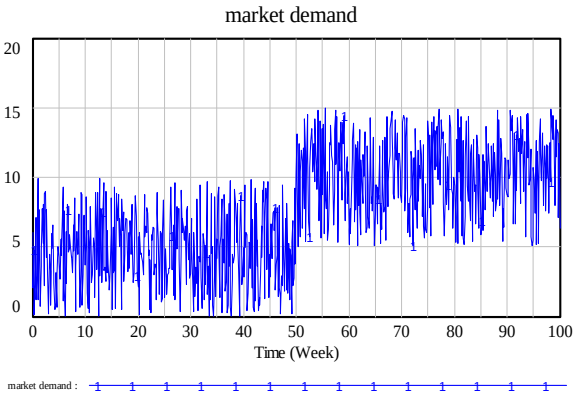


（b）Inventory changes before market demand's disturbance

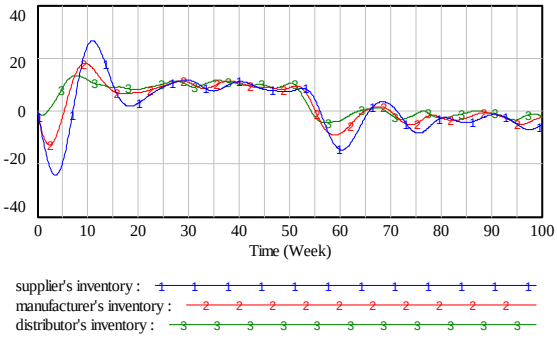


（c）Delivery ratio changes before market demand's disturbance

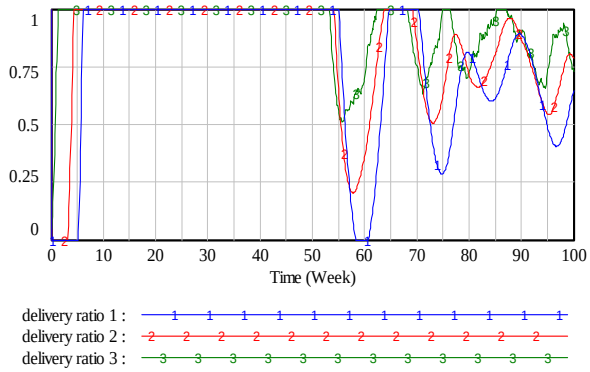
Figure 2. Systemic behavior before market demand's disturbance



（a）Market demand after disturburbance



（b）Systemic behavior after disturbance



（c）delivery ratio changes after market demand's disturbance

Figure 3. Systemic behavior after disturbance

B. Order cycle time's influence to systemic behavior

Generally speaking, increasing order cycle time can influence the delivery ratio of the whole supply chain. However, for agile supply chain, the fact is not as so. When the value of supplier's order cycle time is only changed (but the manufacturer's order cycle time and the distributor's order cycle time is unchanged), the curve line of supplier's inventory changes accordingly, but the curve liners of the manufacturer's inventory and the distributor's inventory don't change,which explains supplier's order cycle time has only inluence on supplier'delivery,not on other delivery.

TABLE I.
STATISTICS OF AVERAGE DELIVERY RATIO UNDER DISTURBANCE

strategies	Delivery ratio 1	Delivery ratio 2	Delivery ratio 3
Before disturbance	0.9424	0.9624	0.9930
After disturbance	0.7683	0.8347	0.9164

Fig. 4 (a1) and (a2) is a systemic behavior chart when distributor's order cycle time is changed as 10 ,and supplier's order cycle time and manufacturer's order cycle time is unchanged (they are still 2). From Fig. 4 (a1) and (a2),we can see that with increasing distributor's order cycle time to 10,the curve of distributor's inventory lies down axis, which states distributor's delivery (it is also can be seen from delivery ratio 3) can not meet market demand. However , the curves of supplier's inventory and manufacturer's inventory are still above axis, almost unchanged, which states supplier's and manufacturer's delivery (it is also can be seen from delivery ratio 1 and delivery ratio 2) can still meet downstream demand.

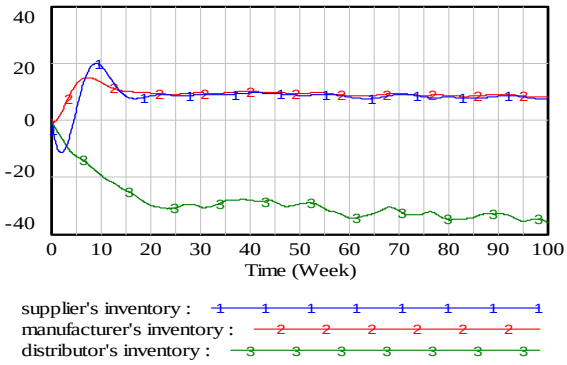
Fig. 4(b1) and (b2) is a systemic behavior when the value of supplier's order cycle time and manufacturer's order cycle time is changed as 10,and distributor's order cycle time is unchanged (still 2).From Fig. 4(b1) and (b2),we can see that when change supplier's order cycle time and manufacturer's order cycle time as 10,the two curves of supplier's inventory and manufacturer's inventory lies down horizontal axis, which states supplier's delivery and manufacturer's delivery (it is also can be seen from delivery ratio 1 and delivery ratio 2) can not meet downstream demand. However, the curve of distributor's inventory is almost unchanged, still above horizontal axis , which states distributor's delivery (it is also can be seen from delivery ratio 3) can still meet market demand.

All these explain that for supplier, manufacturer and distributor, changing whose order cycle time only whose delivery, that is to say, all delivery ratio of the whole supply chain can be increased through changing supplier's order cycle time, manufacturer's order cycle time and distributor's order cycle time simultaneously.

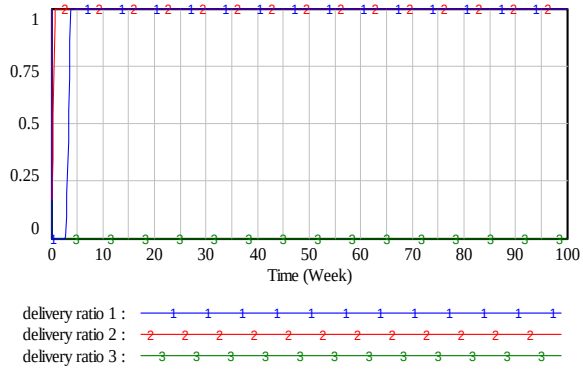
To deeply illustrate the relationship between systemic behavior and order cycle time, we analyzed statistics about delivery raio,which can be seen from Table II.

Related explanation: order cycle time (10,10,2) expresses supplier's order cycle time,manufacturer's order cycle time are 10, distributor's order cycle time is 2; order cycle time (2,2,10) expresses supplier's order cycle time and manufacturer's order cycle time are 2 respectively, and distributor's order cycle time is 10.

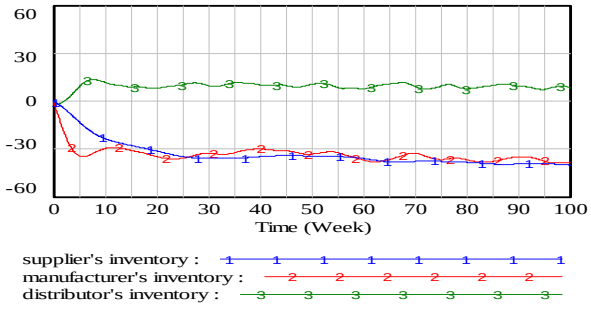
All of these results demonstrate that for agile supply chain, the strategy of changing order cycle time only improves the delivery ratio of local supply chain, not of the whole supply chain. The delivery ratio of the whole supply chain can be increased through reducing all order cycle times.



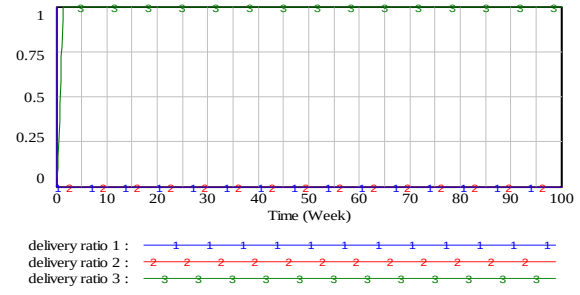
(a1) Systemic behavior when only change distributor's order cycle time as 10



(a2) delivery raio changes when only change distributor's order cycle time as 10



(b1) Systemic behavior when change supplier's and manufacturer's



(b2) delivery raio changes when change supplier's and manufacturer's order cycle time as 10 respectively

Figure 4. Influence of order cycle time to systemic behavior

C. Target inventory's influence to systemic behavior

There are 3 kinds of target inventories, which are of supplier, manufacturer and distributor. Target inventory's influence to systemic behavior is analyzed through changing 3 strategies of target inventories.

When the value of supplier's target inventory is changed, the curve line of supplier's inventory moves accordingly (when increase its value, the curve of supplier's inventory moves up, and lower its value, the curve of it moves down),but the curve liners of manufacturer's inventory and distributor's inventory almost unchanged including its shape, which means supplier's target inventory has influence to the delivery of supplier, not to the delivery of manufacturer and distributor. All these are similar to the influence of manufacturer's target inventory and distributor's target inventory to their inventories.

Fig. 5(a1) and (a2) is systemic behavior when the value of supplier's target inventory is changed as 10,and the values of manufacturer's inventory and distributor's inventory are still 20 ,which shows the changes of simulation,including supplier's inventory, manufacturer's inventory, ditributor's inventory and delivery ratio 1, delivery ratio 2, delivery ratio 3. From Fig. 5(a1) we can see that when reduce supplier's target inventory , the curve of supplier's inventory moves down slightly, but the two curves of manufacturer's inventory and distributor's inventory move hardly. At the same time, the curve of delivery ratio 1 changes clearly,and the curves of delivery ratio 2 and delivery raio 3 show little change.

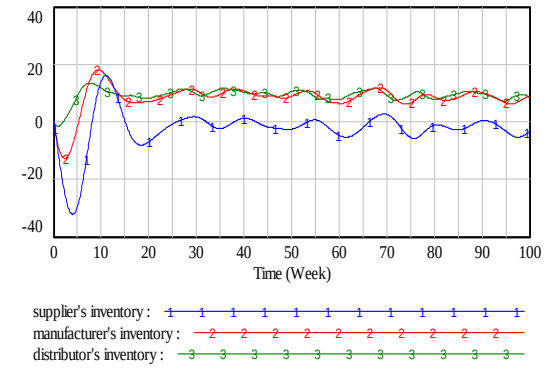
Fig. 5(b1) and (b2) is systemic behavior when the values of manufacturer's target inventory and distributor's target inventory are changed as 10, and supplier's target inventory is still 10. It can be seen from Fig. 5(b1),when we reduce manufacturer's target inventory and distributor's target inventory, the two curves of manufacturer's inventory and distributor's inventory accordingly move down ,and their delivery ratio (delivery ratio 2 and dlivery raio 3) become lower,not to meet delivery requirements.

To explain concretely the phenomena, we calculated the values of delivery ratio including supplier's target inventory changed and unchanged, which can be seen from Table III.

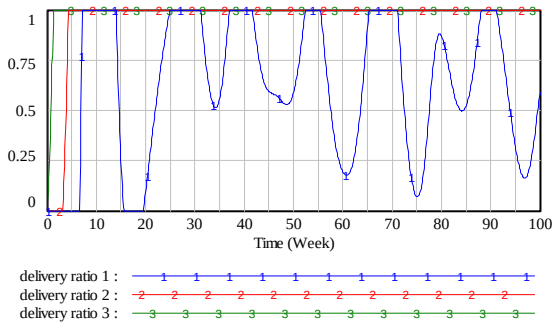
Related explanation: Target-inventories (20,10,10) expresses supplier's target inventory is 20,manufacturer's target inventory and distributor's target inventory are 10 respectively; Target-inventories(10,20,20) expresses supplier's target inventory is changed as 10, and manufacturer's target inventory and distributor's target inventory are still 20 respectively.

TABLE II.
STATISTICS OF AVERAGE DELIVERY RATIO UNDER 2 STRATEGIES

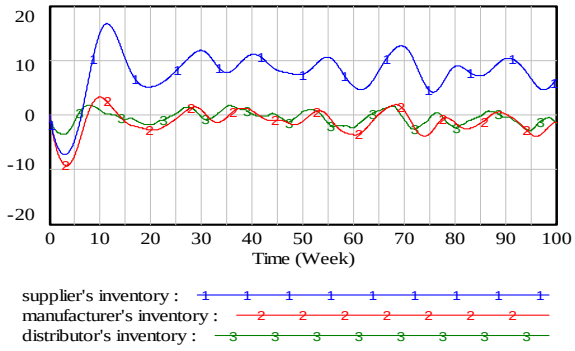
strategies	Delivery ratio 1	Delivery ratio 2	Delivery ratio 3
order cycle time (10,10,2)	0.0000	0.0000	0.9930
order cycle time (2,2,10)	0.9626	0.9972	0.0000



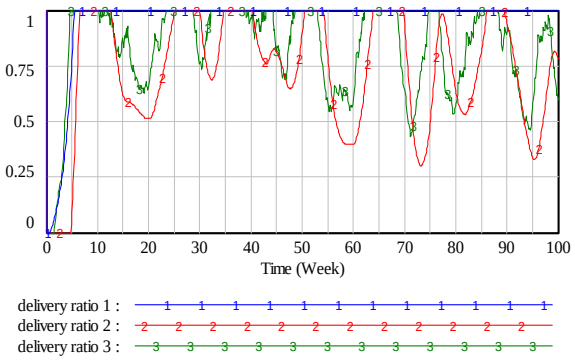
(a1) Systemic behavior when only change supplier's target inventory as 10



(a2) delivery ratio changes when only change supplier's target inventory as 10



(b1) Systemic behavior when change manufacturer's and distributor's target inventory as 10 respectively



(b2) delivery ratio changes when only change supplier's target

Figure 5. Influence of target inventory to systemic behavior

From table 3, we can see when the value of supplier's target inventory is changed at 10, delivery ratio 1 has been changed ,but delivery ratio 2 and delivery ratio 3 unchanged. All of these results demonstrate, the delivery ratio of the whole supply chain can be improved through increased different target inventories.

TABLE III.
STATISTICS OF AVERAGE DELIVERY RATIO UNDER 2 STRATEGIES

strategies	Delivery ratio 1	Delivery ratio 2	Delivery ratio 3
Target-inventories (20,10,10)	0.9628	0.7244	0.8339
Target-inventories (10,20,20)	0.6255	0.9624	0.9930

IV. CONCLUSIONS

From this study, there are a number of conclusions can be drawn. They are as follows:

(1) The delivery of Agile supply chain is stable, whether it is in market demand's disturbance or not.

(2) Traditionally, increasing order cycle time can promote the delivery ratio of the whole supply chain .However ,for agile supply chain, order cycle time only affect on local supply chain, not on the whole supply chain. The delivery ratio of the whole supply chain can be increased through reducing all order cycle times.And there is a appropriate value of order cycle time which can make the whole inventory in supply chain reach minimum but the delivery can be meet.

(3) For agile supply chain, the strategy of changing target inventory increases only the delivery of local supply chain, not of the whole supply chain. The delivery ratio of the whole supply chain can be increased through changing different target inventory.

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