System Dynamics Modeling and Simulation for Competition and Cooperation of Supply Chain on Dual-Replenishment Policy

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***Abstract*—The need for holistic modeling efforts that satisfy the increasing supply chain enterprise at a strategic level has been clearly recognized by industry first and by academia recently. In order to increase the profitability of the entire chain, strategic decision-makers need comprehensive models to guide them to make efficient decision. The determination of optimal network configuration, inventory management policies, supply contracts, distribution strategies, supply chain integration and information technology are prime examples of strategic decision that affect the long-term profitability of the entire supply chain. With the main aim of supply chain management being to maximize the profits of supply chains, we depict a benchmark model which describes two supply chain competition behaviors under the fluctuation demand situations. On that basis, we design the cooperation contract between the chains for retailers' inventory replenishment, and moreover, extend this cooperation contract to dual replenishment policy in order to heighten the profits of supply chain and its members in development. Found by the system dynamics simulation, this chain cooperation contract makes profit increasing to some degree, but inventory fluctuation of the supply chain members will be aggravated and the inventory cost will be increased. Consequently, we analyze the key issue of strategic supply chain management in depth, that of regulation parameter. Finally, we demonstrate the applicability of contract model on dual-replenishment policy through the application of computer simulation.**

***Index Terms*—System dynamics, Dual-replenishment policy, Competition and Cooperation, Contract, Supply chain**

I. INTRODUCTION

An increasingly vocal and popular sentiment holds that the nature of competition in the future will not be between companies but rather between supply chains, supply chain has become an important way to winning the future[1-4]. The rise of global manufacture and information technology booming, makes the structure of the supply chain become more complex, and there are plenty of research fields involved. Inventory management is one of the research hot points for both domestic and foreign scholars. Cachon[5-7] analyzed the competition and cooperation strategy of supplier and retailer from a single chain angle. Towill[8] studied inventory competition of two symmetrical supply chain that each consists of a manufacturer and retailer, but he didn't consider cooperation. Bernstein[9-12] studied the equilibrium state of the competing retailers in the decentralized supply chain under uncertainty demand. Zhang and Xiao[13-15] made a large contribution on supply chain network competition, but they just considered price, service, and demand.

Most of these studies is from a single standpoint, which only considered the across-competition or only considered replenishment. Based on the above studies, under demand uncertainty conditions, this paper constructs model of competition between supply chains, each consists of one manufacturer and one retailer. Considering inventory level and profit fluctuation, we establish an cooperation contract based on inventory replenishment, and extend the contract to the dual-replenishment policy to achieve win-win situation. Finally, we furtherly indicate the effectiveness of the model by contrasting the simulation results.

II. A SYSTEM DYNAMIC MODEL OF THE TWO-ECHELON SUPPLY CHAIN COMPETITION

We assume that the competition model is composed by two supply chains and each chain is composed by a manufacturer and a retailer. The product which managed by the two chains are homogeneous and can be substituted completely. The competition between two supply chains is normal distribution in the consumer market. As shown in Fig 1.

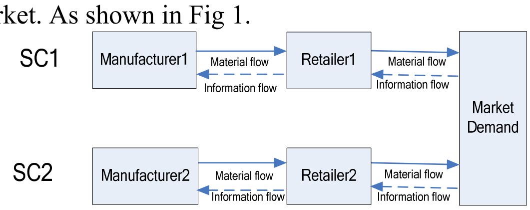

Figure1. Structure of the two-echelon supply chain competition

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In each supply chain, when retailers place an order to the manufacturer, it always uses the periodic inspection replenishment strategy, that is to check inventory state periodically. There is no replenishment between the same node in two supply chains, and the relationship between the two nodes is fully competitive. If the existing storage is above the replenishment point, there is no supplement when checking, otherwise the retailer will replenish the stock. Fig. 3 presents the system dynamics model of supply chain competition.

The actual replenishment behavior is usually triggered by the retailer's supplement signal. When retailer's accumulative order is above or equal to its economic orders quantity , or retailer's inventory is below or equal to its orders points, retailer's supplement signal will be one, triggering replenishment. In this moment, retailer's actual replenishment is minimum, and yet, replenishment quantity is zero. The DYNAMO equation of retailer replenishment signal can be shown as:

$$\text{REPSIGNALR.K}=\begin{cases}1, & \text{ORDERRA.K} \geq \text{EOQR.K or INVR.K} \leq \text{ORDERPR.K} \\ 0, & \text{ORDERRA.K} \leq \text{EOQR.K and INVR.K} \geq \text{ORDERPR.K}\end{cases} \quad (1)$$

The DYNAMO equation of retailer's actual replenishment quantity can be shown as:

$$\text{REALREPR.KL}=\begin{cases}0, & \text{REPSIGNALR.K} \neq 1 \\ \text{MIN(INVM.K,EOQR.K)}, & \text{REPSIGNALR.K}=1\end{cases} \quad (2)$$

In this paper, our research only relates to the stock which have been finished in two-echelon supply chain. In this stock model of manufacturer, we don't consider other cost of raw material and pay close attention to the price of raw material which has a direct relationship with the stock of finished products. Under this competition mode, retailer' inventory is determined by the shipment rate(SALER) and receiving rate(SHIPTOR) of the retailer, and its DYNAMO equation is shown as:

$$\text{INVR.K=INVR.J+DT*(SHIPTOR.JK-SALER.JK)} \quad (3)$$

Two supply chains share the same market, but they have different market occupation ratio. We assume that the DYNAMO equation of demand and price is:

$$\text{DEMANDSC1.K=DEMAND.K-}\beta 1\text{*PRICER1.K+}\beta 2\text{*PRICER2.K}$$
$$\text{DEMANDSC2.K=DEMAND.K-}\beta 1\text{*PRICER2.K+}\beta 2\text{*PRICER1.K} \quad (4)$$

Among them the total market demand quantity is nonnegative and random variable, both distribution function and density function are continuous. The market demand of SC1(supply chain 1)and SC2(supply chain 2) are determined by the retail price of product of R1(Retailer 1) and R2(Retailer 2). When the price of product of R1 increases, its market demand will be decreased, we call it as crowding out effect. When the price of R2's products rises, its rival's market demand maybe increases, we call it as attraction effect. The parameters of β1and β2 are the measurement of this two effects respectively.

In the model, shown as in figure 1, before the arrival of marketing circling, every manufacturer and retailer will make a decision of production and order according to the expectation of sales, market demand, and the level of stock of themselves. There the demand of retailers from manufacturers depends on the demand of customers. Manufacturers delivery the products to retailers, retailers receive commodities, and sell them to customers. Each manufacturer's cost mainly involves four sections: the treatment cost of orders which manufactures have received, the purchase cost of raw material when manufacturers purchased, the production cost which manufacturers make the raw material for production and the storage cost of production and raw material. The manufacturers' income is that it sells products to the retailer and then obtains income. Its profits are the difference of total income and total cost. Each retailer's cost mainly involves three sections: the purchase cost when retailers buy products from manufacturers, the order cost when the stock is not enough, accordingly, the existing inventory cost if stocks have the rest. The retailer's receipts equals to sales receipts, its total profits is the difference of total revenue and total cost. The total profits of entire supply chain is the sum of total profits of manufacturers and retailers.

III. A SYSTEM DYNAMICS MODEL FOR ACROSS-CHAIN COOPERATION CONTRACT BASED ON RETAILERS' INVENTORY REPLENISHMENT

The foregoing model, which is inner-chain cooperation mode, just uses the way of interior chain replenishment to meet the upstream's demand. Owing to the single target that increases their own supply chain profits, the winning node of the supply chain may be out of stock. Conversely, the failure node may appeared to the rest of the stock. We will present an across-chain cooperation contract based on retailers' inventory replenishment to coordinate the supply chains under competition. As shown in Fig 2.

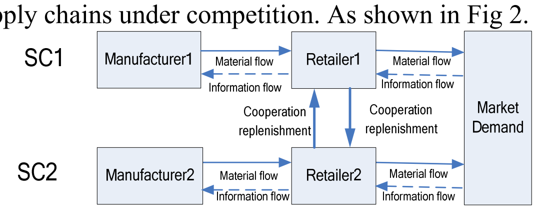

Figure2. Structure of across-chain cooperation

we suppose that the competitive node is near in geographical position and take no account of replenishment lead time and replenishment delay. The situation that a retailer is out of stock and another is surplus can trigger the across-chain cooperation contract. The surplus or not will be judged by the difference of the customer demand and retailers' inventory. When one difference greater than zero and another is less than zero, cooperation signal will be triggered and two retailers of across-chain begin to make a cooperation. According to the cooperative product price and batch, we coordinate two retailers by adding across-chain replenishment cooperation contract, which make retailers, manufacturers and total supply chain to win-win situation.

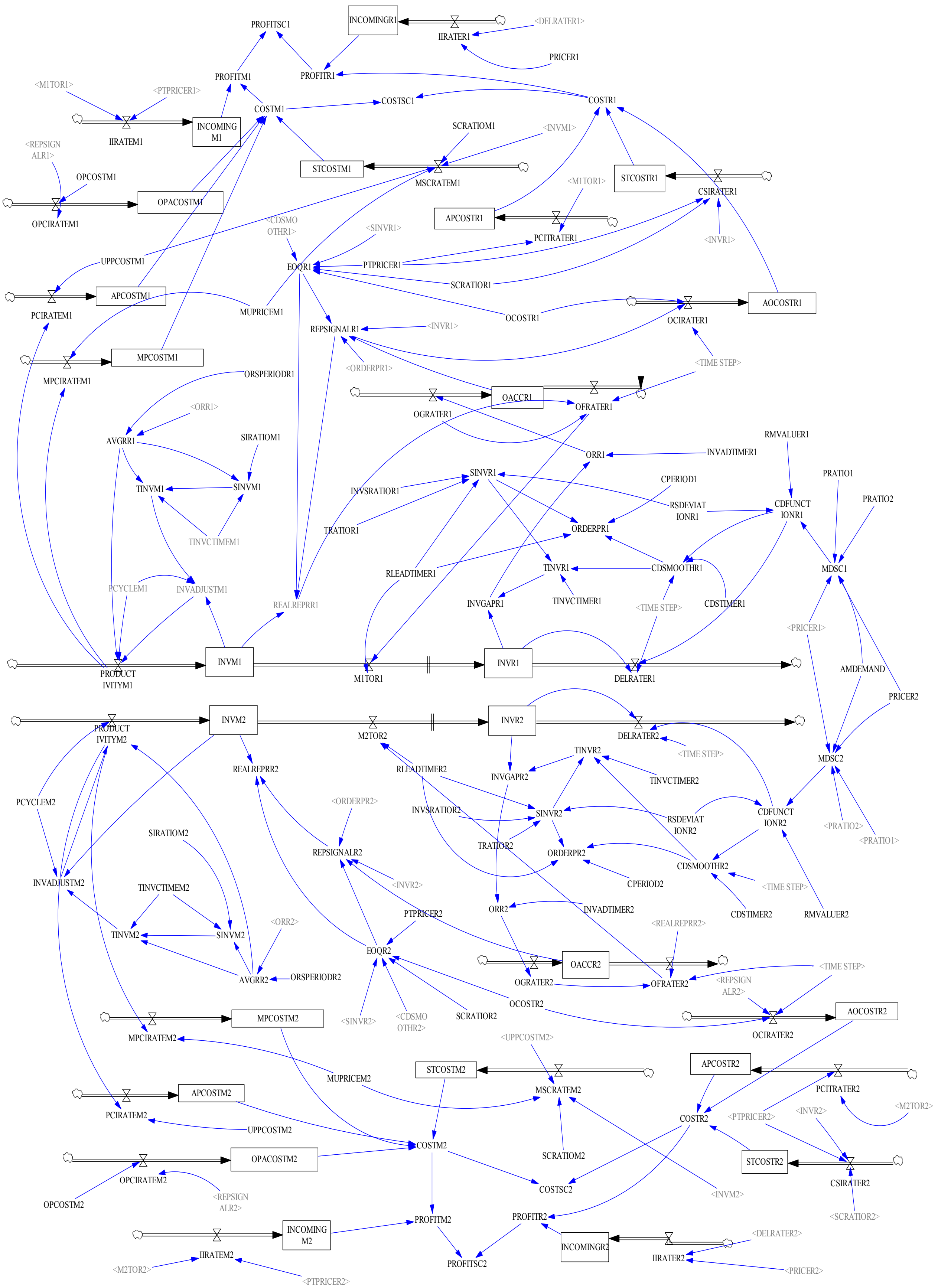

Figure 3. Causal loop diagram of supply chain competition

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Fig. 7 presents the model of across-chain cooperation contract. Difference(DISPERSION) is the differential of retailers inventory(INVR)and customer demand function (BDEMANDF). The DYNAMO equation for cooperation signal(CSIGNAL) can be shown as:

$$\text{CSIGNAL.K}=\begin{cases}\text{CSIGNAL1.K} & \text{DISPERSION1.K}>0 \text{ and DISPERSION2.K}<0\\ \text{CSIGNAL2.K} & \text{DISPERSION1.K}<0 \text{ and DISPERSION2.K}>0\end{cases} \quad (5)$$

If R2 makes a replenishment to R1, Cooperation signal 1 will be triggered. When Difference 1 (DISPERSION1) is above zero and Difference 2(DISPERSION2) is below zero they will have cooperation, in the meantime, cooperative replenishment quantity is the minimum absolute value of Difference 1 and Difference 2. Conversely, there will have no cooperation.

If R1 makes a replenishment to R2, Cooperation signal 2 will be triggered. When Difference 2(DISPERSION1) is above zero and Difference 1(DISPERSION2) is below zero they will have cooperation, in the meantime, cooperative replenishment quantity is the minimum absolute value of Difference 1 and Difference 2 and vice versa. The single cooperative product price is based on the across-chain cooperation contract. The replenishment between retailers is triggered by cooperation signal. The DYNAMO equation of replenishment quantity(RTOR) can be shown as:

$$\text{RTOR.K=MIN(ABS(DISPERSION1), ABS(DISPERSION2))} \quad \text{CSIGNAL1=1} \quad (6)$$

Determined by replenishment quantity of across-chain, the cooperative product price(CPRICE) will be higher than the primary sale price (TPRICER) of own chain replenishment. We assume that a cooperative product price will be for 110% of the original products' primary sale price when replenishment quantity achieved 100 or more, a cooperative product price will be 130% of the original products' primary sale price when replenishment quantity is less than 100. The DYNAMO equation can be shown as:

$$\text{CPRICER1.K}=\begin{cases}\text{TPRICER1*(1+10\%)} & \text{R2TOR1}>100\\ \text{TPRICER1*(1+30\%)} & \text{R2TOR1}<=100\end{cases} \quad (7)$$

In this paper we use the system dynamics simulation with the simulation software Vensim, the profit is the measure index of model. The simulation period is 100 weeks and the step is 1 week. The customer demand of two chains follows a normal distribution [600, 30]. The replenishment lead time of R1 and R2 is 1 week, the goal inventory covered-time of R1 and R2 is 3 weeks, the inventory adjustment time of R1 and R2 is 4 weeks, the order requirement smooth cycle of R1 and R2 is 3 weeks, price coefficient is 2 and 4 respectively, production cycle of M1 and M2 is 1.5 weeks, safety

stock coefficient of M1 and M2 is 0.2, the inventory covered-time of M1 and M2 is 2 weeks, the inventory adjustment time of M1 and M2 is 2 weeks.

In the simulation environment above mentioned, by contrasting the competition model shown as Fig.3 and the across-chain cooperation model shown as Fig.7 in the simulation(the results shown as Fig. 4, Fig. 5 and Fig. 6), we can conclude that two chain overall profits with across-chain cooperation are higher than pure competition significantly. As the increasing of demand satisfaction rate, It indicated that across-chain cooperation can improve the competitive power of supply chain.(Line 1 is competition, line 2 is across-chain cooperation).

From below figure we can conclude that the orders request is higher under across-chain cooperation and both chain's profits make a increasing much more than before.

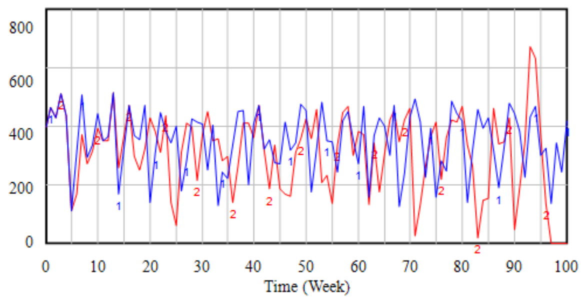

Figure 4. Contrast of orders request

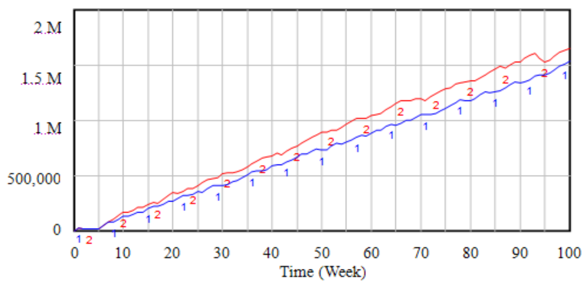

Figure 5. Contrast of SC1's profit

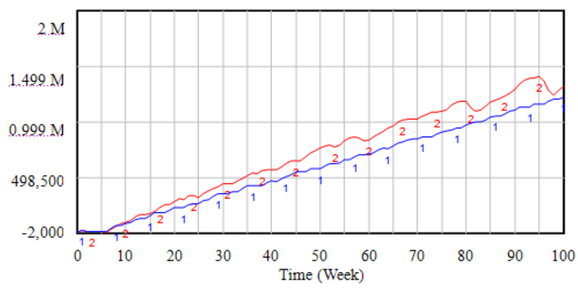

Figure 6. Contrast of SC2's profit

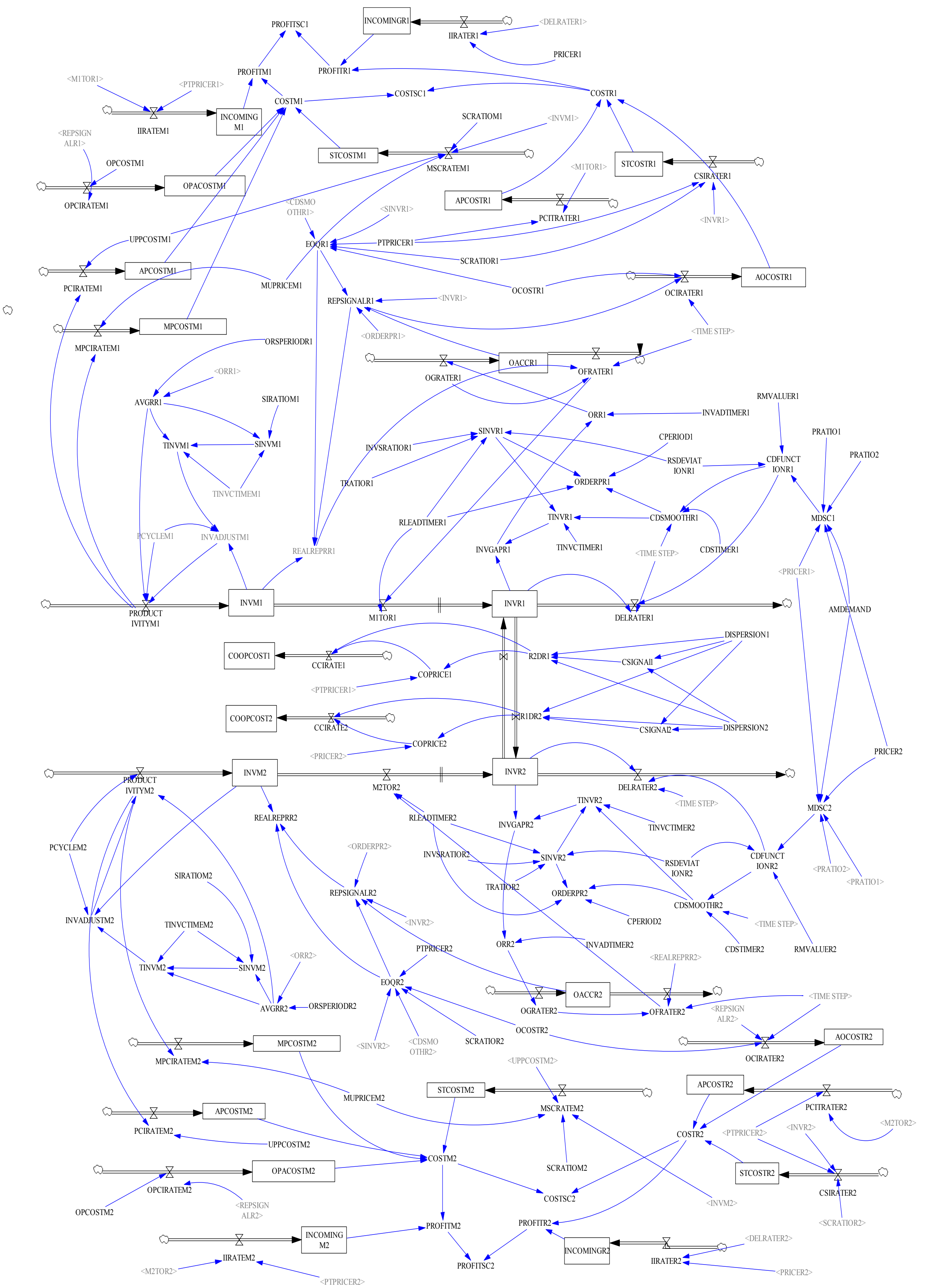

Figure 7. Causal loop diagram of across-chain cooperation

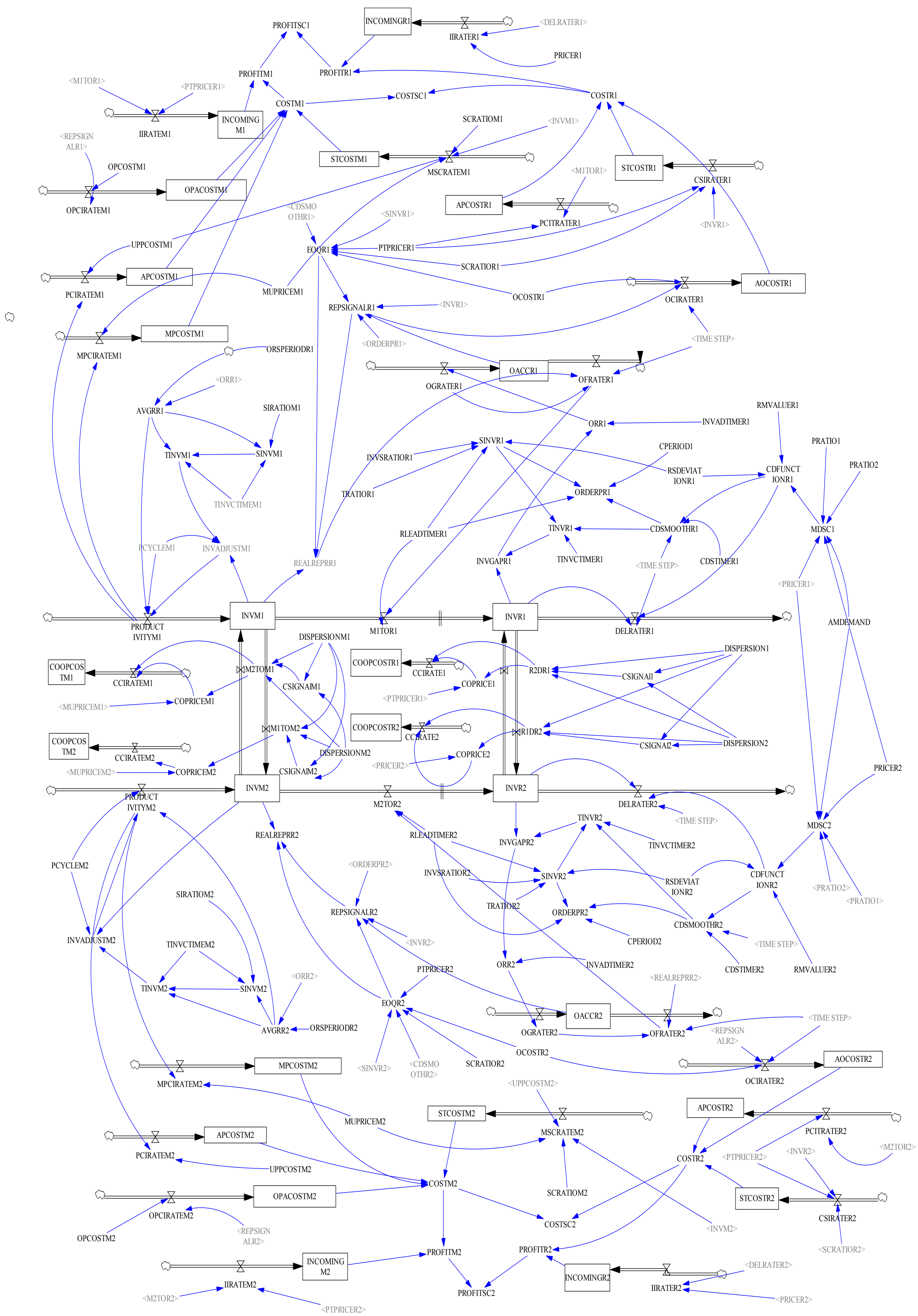

Figure 8. Causal loop diagram of across-chain cooperation based on dual-replenishment

IV. A System Dynamics Model Of Across-The-Chain Cooperation Contract Based On Dual-Replenishment

On the basis of retailers' across-chain cooperation, we introduce across-chain cooperation contract between the manufacturers by the same, and establish the model of across-chain cooperation contract of manufacturers and retailers, shown as in Fig 9, to furtherly improve the overall profits.

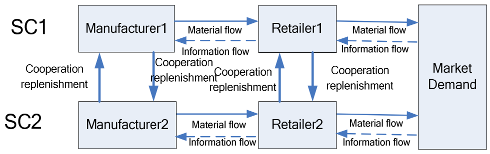

Figure9. Structure of dual-replenishment cooperation

Suppose that it takes the way of across-chain replenishment as the manufacturer shortage, unit prices of across-chain replenishment raw materials is according to the quantity of cooperation. When it achieves 200 or more, unit price of cooperation raw materials is 110% of the original price, when it is less than 200, unit price of cooperation raw materials is for 130% of the original price.

For comparing with the benchmark competition model, retailers' replenishment, and inventory dual-replenishment, we stimulate and make contrast with each other. Shown as in Fig 10, Fig 11, Fig 12, Fig 13, the profit of the supply chain using dual-replenishment furtherly improves. Although the cooperation cost in the total cost of manufacturers and retailers improved, and inventory cost of each node increased owing to more demands, across-chain cooperation replenishment reduces other costs, and offsets additional cost, and the total cost will be reduced eventually.

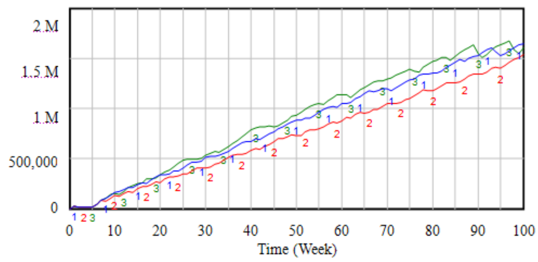

Figure 10. Contrast of SC1's profit
(1:single-replenishment 2: competition 3: dual- replenishment)

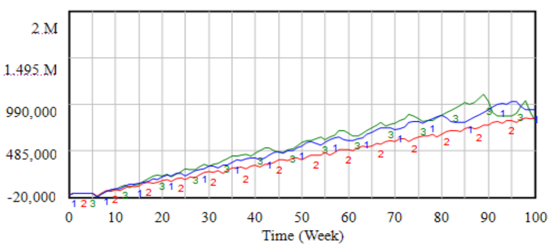

Figure 11. Contrast of R2's profit
(1:single-replenishment 2: competition 3: dual- replenishment)

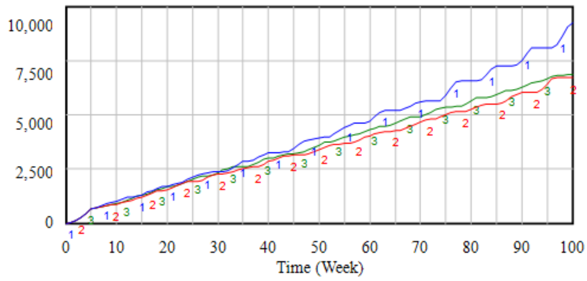

Figure 12. Contrast of M1's inventory cost
(1: dual- replenishment 2:single-replenishment 3:competition)

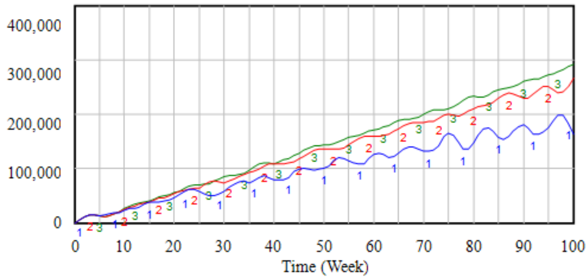

Figure 13. Contrast of M1's cost
(1: dual- replenishment 2:single-replenishment 3:competition)

Shown as in Figure 14 simulation results, the manufacturers and retailers will not accept replenishment at the same time, namely out-of-stock will not be happened simultaneously. As a node shortage, its upstream (or downstream)node would be in a state of ample supply or a state of being cooperate replenishment.

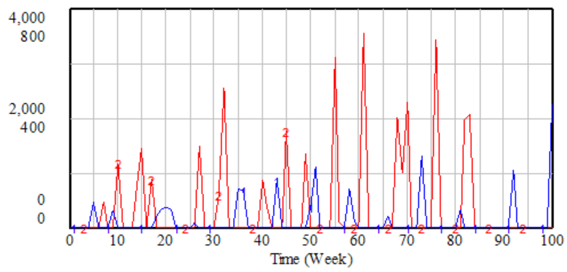

Figure 14. Contrast of replenishment
(1: M2 delivers to M1 2: R2 delivers to R1)

Across-chain cooperation make node's profits and total chain's profits improved, but owing to the increasing demand, inventory fluctuates more frequently, inventory costs also be increased, which is the focus of further research in future.

V. Conclusions

In order to enhance profit, we present system dynamics to construct supply chain competition model and across-chain cooperation model based on retailers' inventory replenishment, and then we extend the across-chain cooperation model to the dual-replenishment policy on both manufacturers and retailers to enhance more profit. The study shows the profits of the total supply chains and their nodes will increase step by step when competition transforms into cooperation, single replenishment policy transforms into dual-replenishment policy. Owing to the continuous improvement of the demand, the fluctuation of inventory changes a lot and inventory cost also increases. From simulation results, we can see that replenishment may not occur at the same time is consistent with reality. The improved model can be furtherly used to analyze many supply chain policy and answer questions about the operation of supply chains, using total supply chain profit as the measure of performance. The model can furtherly be tailored and used in a wide range of manufacture supply chains. Thus, it may be proved useful to policy-makers/regulators, and decision-makers disposing a wide spectrum of strategic supply chain management issues.

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