System Dynamic Analysis on Operation Modes of Agri-food Supply Chain

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***Abstract* — This study aims to analyze agri-food supply chain operation modes based on system dynamics. We present and analyze three main modes in China as DDR(core of distributor), SS(core of supermarket) and SC (core of supplier) mode. We choose dominant DDR and potential SS mode, analyze detailed flowcharts and compare relationship of inventory level and order under stochastic demand information based on system dynamics theory. Simulation results show SS mode has lower inventory level, less inventory fluctuation and decreased bull-ship effect than DDR mode. Thus agri-food supply chain with core of supermarket or retailer would be more effiecient and cost-effective.**

Keywords - Agri-food ; Supply chain; Operation Mode; Dynamics

I. INTRODUCTION

In China, agriculture is a fundamental sector of national economy. Recently, large price fluctuations of agricultural products in China make it become a research hotspot on how to reduce the inventory levels of each node enterprise in circulation of agricultural products under the premise of a high level of service. The perspective of supply chain may well be a useful idea to regulate circulation of agricultural products [1]. Agricultural products flow along a mesh chain from the farmers, processing companies, distribution centers, wholesalers, and retailers to consumer, and the chain structure of this network can be defined as the agri-food supply chain.

Agri-food supply chain encompasses all activities associated with the flow and transformation of agricultural products from the farmland to dining table, as well as the associated information flows [2]. Information sharing is an essential factor in establishing an effective agri-food supply chain [3,4]

At present, the main mode of supply of agricultural products in China would be distributors or wholesalers, which could not respond quickly to the end user ' s (customer) needs and timeliness of the mode is not as efficient as the people expect.

Some scholars present agri-food supply chain based on the leadership of supermarket, in this mode, retailer (supermarket) would proactively look for the chance to cooperate with fewer suppliers so as to keep a long-term strategic relationship. This mode is partly proved its time-efficiency and demand response by some theories and methods like game theory. Also there has been considerable research in the field of system dynamics over the last decade concerned complicated systems including supply chain [5,6], inventory level and bull-whip effects becomes more and more important observing indicator to evaluate the efficiency of supply chain[7,8].

However, few literatures shed light on operation modes of agri-food supply chain based on system dynamics. Because of the general characteristics of dynamics, complexity and retardance in agri-food supply chain, similar to the general supply chain, in this paper, we aim to apply system dynamic analysis to the different modes of agri-food supply chain. In detail, we discuss the relationship of inventory levels and order in random demand information based on different mode of agri-food supply chain, so as to figure out which is the more efficient and effective mode and the mechanism of this one based on Chinese practice.

II. MAIN MODES OF AGRIFOOD SUPPLY CHAIN IN CHINA

Currently in China, there are three main modes in agri-food supply chain, in which there are a sort of key chain members. The first mode is controlled by wholesalers, and we call it "DDR mode". Hereby, D, D and R respectively represent dealers (farmers and/or processors), distributors (wholesalers) and retailers. This mode is based on the dominant role of middle link of the chain.

The second is named as "SS mode", in which supplier is subordinated to the supermarket (or retailer). Last one is called "SC mode", where S means supplier and C represents consumers. Before analyzing the dynamics of agri-food supply chain, it is an initial stage for us to shed light on these modes..

A. DDR Mode

This mode of agri-food supply chain is composed by farmers, processors, wholesalers and retailers from the source of original produce to the final link of the chain to the end user. This would be the traditional and most common mode in Chinese agri-food supply chain. In this

mode, demand and supply are realized by the invisible hand of market mechanism. From the perspective of supply chain, though wholesalers stand at the key position of the entire chain, chain members (agents) work each for themselves, which means it is hard to organize the whole supply chain as an integrated one. Figure 1 demonstrates the mode in detail.

As can be seen from the figure, wholesalers is the dominant link in the chain, they integrate the huge information of produce source from diverse farmers or processors, and they themselves are sorts of distribution markets. For all processors or farmers (we call them dealers), they are termination, and for retailers, they are source of produce. This collecting and distributing function makes wholesalers further intensify their roles in circulation of agri-food. Another reason why they are so powerful in China is due to decades of history of central planning in economy.

Habitual thinking pattern make processor or farmers tend to look for the existing wholesale markets rather than the end user. Admittedly, they seem to be short of the drive to deliver to the last kilometer. Long haul transportation, generally speaking, from the place of origin to the wholesalers (distribution center) is more economical

B. SS mode

SR mode of agri-food supply chain is the emerging trend in circulation in China. İn the mode, supermarkets (retailers) replace the dominant position of wholesalers in the whole chain. As can be seen from the Figure 2, wholesalers disappear form the supply chain, which means supermarkets bypass the redundant link and order the agri-food directly from processors or farmers, even they would customize their orders with the original source. From the supply chain perspective, because of the lack of intermediate link of wholesalers, the information flow and logistic response time would be shorten to some degree, thus this timliness make the real demand and supply keep in good step with market. With information communication between supermarkets and suppliers, suppliers would make sense of the real demand of end users and keep their inventory in a appropriate level.

Another benefit of this mode is to consumers. With the one middle link dropped, consumers would buy produce at cheaper price [3]. Take Wu Mart as example, this company becames China's fourth-largest retailer by sales with 722 supermarkets and stores in China till March 31,2015, is typical of a supermarket chain with room to grow.

This company focus on Northern China market, and occupied 33.33% markrt segmentaiton in Beijing with 289 stores. With its centralized purchasing mode, it cooperates and keep long-term relationship with suppliers and intensifies the regional concentration ratio. The most notable feature of the company’s purchasing is agriculture-supermarket jointing project, which reduces circulation links and cost, and builds new circulation modes for agri-food. In the mode, Wu Mart identifies Shandong , a famous produce province, as main purchasing base, and some provinces of Hebei, Sichuan, Fujian, Xinjiang, Hainan as charactistic vegetable and fruit bases, and develops qucik-response-order mechanism with leadtime shorten.

C. SC mode

With the development of internet and big data technology, suppliers, especially big processors, tend to directly sell to the end users. As demonstrated in Figure 3, some of these companies gather demand information online and pull the processing and logistics activities. DCs, distribution centers are operated by their own or outsourced to the third party logistics (TPL). Some TPLs would develop as the fourth party logistics (FPL) when they could provide the integrated solution for their customers.

Some companies carry out O2O (online to offline) strategy to give customers good personal experience and attract them to put on orders. This is not only a kind of new marketing method which connects and engages with consumers online and appeal them to the physical store, but also a brand new supply chain idea which means gathered information flow would be perfectly integrated with logistics flow.

In recent two years, huge capitals have been invested in diverse O2O projects. However, this mode is not mature enough and that is why we subsequently merely discuss the first two modes.

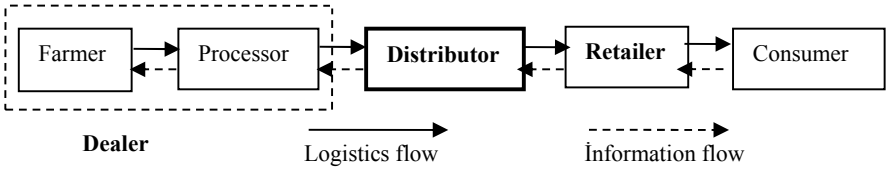

Figure.1 The DDR mode of agri-food supply chain

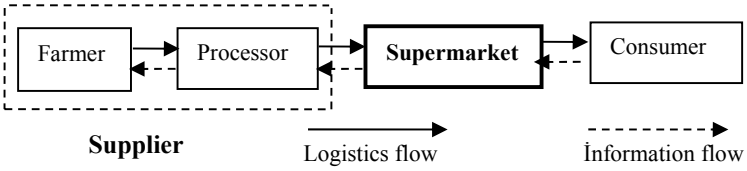

Figure.2 The SS mode of agri-food supply chain

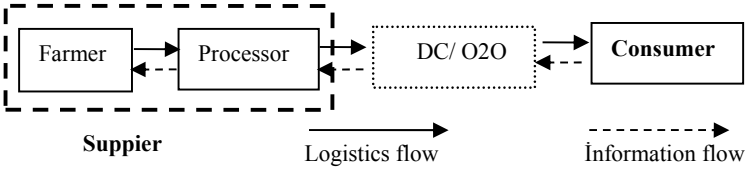

Figure.3 DDR Flowchart

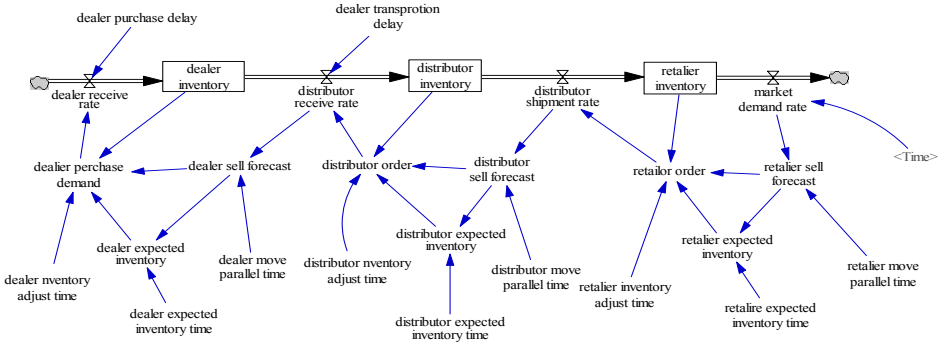

Figure.4 SS Flowchart

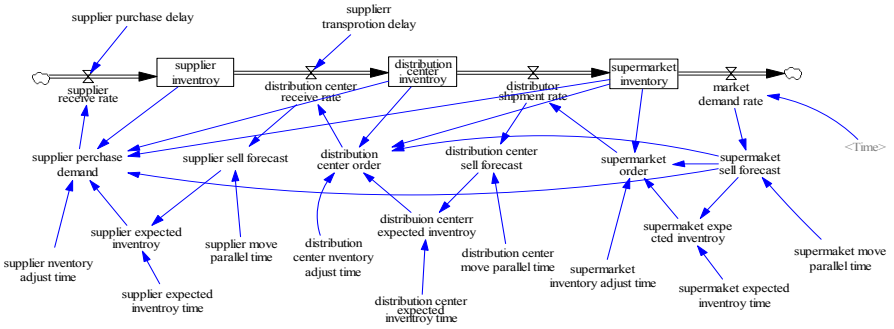

Figure.5 SS Flowchart

TABLE 1. MAIN MATHEMATIC OR LOGIC FORMULA OF DDR MODE

Variables	Mathematic or Logic Formula
Retailer Order	MAX(0, Retailer Sale Forecast ＋(Retailer Expected Inventory －Retailer Inventoy)/Inventory Adjust Time)
Distributor Order	MAX(0, Distributor Sale forecast ＋(Distributor Expected Inventory－Distributor Inventoy)/Inventory Adjust Time)
DealerDemand	MAX(0, Dealer Sale Forecast ＋(Dealer Expected Inventory－Dealer Inventoy)/Inventory Adjust Time)

TABLE II. Main mathematic or logic formula of SS mode

Variables	Mathematic or Logic Formula
Retailer Order	MAX(0, Retailer Sale Forecast＋(Retailer Expected Inventory －Retailer Inventoy)/Inventory Adjust Time)
Supplier Demand	MAX(0, Supermarket Forecast ＋(Supplier Expected Inventory ×2－Supplier Inventory－ Supermarket Inventoy)/Inventory Adjust Cycle)

III. SYSMATIC DYNAMICS MODEL OF AFS**C**

A. System Modeling Description

The purpose of system modelling is to compare the bullwhip effects, inventory levels and their fluctuation under stochastic demand between SWR mode and SR mode.

As discussed, the mental mode of SWR is that all agents engage in their own business, they place theit own order based on their own forecast of marker rather than other chain members' inventory levels and demand predict. This is the real situation in the most markets. Mental modal of SR mode, however, is that suppliers, agricolas or processors, make sense of the inventory of retailers (supermarkets), and arrange replenishment for the supermarkets according to some machnism. This similar method in industry is called VMI, which means vendors manage inventory. It aims to minimize the bullwhip effects, optimize inventoty level and cooperate with chain members.

Bullwhip effects refers to such an observed phenomenon as the demand amplified upward the supply chain if looking at firms further back in the supply chain for a product. In other word, there would be larger and larger swings in inventory level in response to some little changes in customer demand. Since Jay Forrester first analyzed the concept in Industrial Dynamics in 1961, it is also known as the Forrester effect. Since the plots of the oscillating demand in figures looks like a cracking whip upstream of a supply chain is, another name for the effect is called the bullwhip effect.

There are three agents in SWR mode, namely, supplier, wholsaler and retailer. In SR mode, there are merely two agents, suppiler and retailer(supermarket). Note that the system inteface of them both begin from the supplier and end at end user.

B. Detailed Syetem Flowcharts

In the DDR mode, there are three inventory levels to be set as in Figure 4 as well as the key role of distributors(wholesalers), bussiness process of the mode, and interaction of information, logistics and agents. Table1 lists the mathematic and logic formulas. In this traditional circulation, the dealers (farmers and/or processors) would not concerned about the inventory level of distributors or retailers, because each agent merely focus on their own. Meanwhile, this chain fails to share the information of supply and demand, which results in every isolated island of information. Under ssymmetric information dealers tend to make unwise decisions which incur the common production and price fluctuated.

In the SS mode，there are two inventory levels to be set for the supplier inventory and supermarket inventory. The great benefit of this mode is information sharing. Suppliers would realize the inventory and sale information of supermarkets, thus can timely replenish order based on the real-time sale data and volume of inventory of supermarket. This mode makes the bull-whip effect as low as possible. Figure 5 demonstrates the detailed flowchart and Table 2 lists the mathematic and logic formulas.

IV. SIMULATION AND RESULTS

A. Setting Parameters

The purpose of system modelling is to compare the bullwhip effects, inventory levels Before running the model, we set relevant parameters and original values of variables. SD is a good experiment space for management decision making, where people can try diverse scenarios, concepts and tactics to adjust the optimization of demand parameters. Comparing other modeling and simulation, it is plain and simple to gain the solution of equation. Table 3 lists parameters and initial values of variables for model simulation.

B. Simulation under Stochastic Demand

We run the modes of two modes as stochastic demand, because stochastic demand reflect the uncertain, diverse and dynamic characteristics of real market. This simulation enovirnment makes results meanful. Figure 6 shows the demand and inventory of agents in DDR and SSR mode . It is apparent that demand order of retailer (supermarket), distributor and dealer (supplier) all represent some nonlinear trendency, and this would be amplified with the order demand of end user and supplier. As the added node of chain, the fluctuation gets larger and larger, the bull-whip effect tends to more and more obvious. Note that we represent the quantificial bull-whip effect (BE) with the ratio of standard deviation（SD）of upstream agent's order and downstream agents' demand as follows:

$$BE = \frac{SD(up.order)}{SD(down.demand)} \tag{1}$$

In Figure 5(a), the number of 1,2,3 represent the inventory change of retailer (RI) , distributor (DTI)and dealer(DLI) , which show complicated nonlinear output

with fluctuation. 4, 5, 6 means retailer order (RO), distributor order (DO) and dealder deamnd (DD). However, in Figure 5(b), the inventory changes of 1 (supermarket,SMI) and 2 (supplier,SPI) are not as significant as above. 3 and 4 represent supermarket order (SO) and supplier demand (SD). As data analysis showed inTable IV, comparing with DDR mode, SS mode of AFSC has less bull-whip effect of supplier at 224.63%, lower inventory level at 2.63% and the inventory fluctuation decreses at 612.50%. Simulation results show the more effecient and effective agri-food supply chain in SS mode

TABLE III. PARAMETERS AND INITIAL VALUES OF VARIABLES FOR SIMULATION

Variables/Parameter	Initial Value/ Instructions
Retailer(Supermarket) Inventory Level	Retailer Inventory =3000Kg, Supermarket Inventory = 3000 kg
Distributor Inventory Level	Distributor Inventory =3000 Kg
Dealer(Supplier) Inventory Level	Dealer Inventory =3000 Kg, Supplier Inventory =3000kg
Market Demand Rate	1000+IF THEN ELSE (Time>4, RANDOM NORMAL(-200, 200 , 0 , 100 , 4) , 0)
Simulation Running Time	200 Days ; dt =1
Observing indicators	Inventory and Order of Retailer (Supermarket) , Distributor, S upplier (dealer);

Figure.5 Inventory and Demand Changes by Mode of AFSC

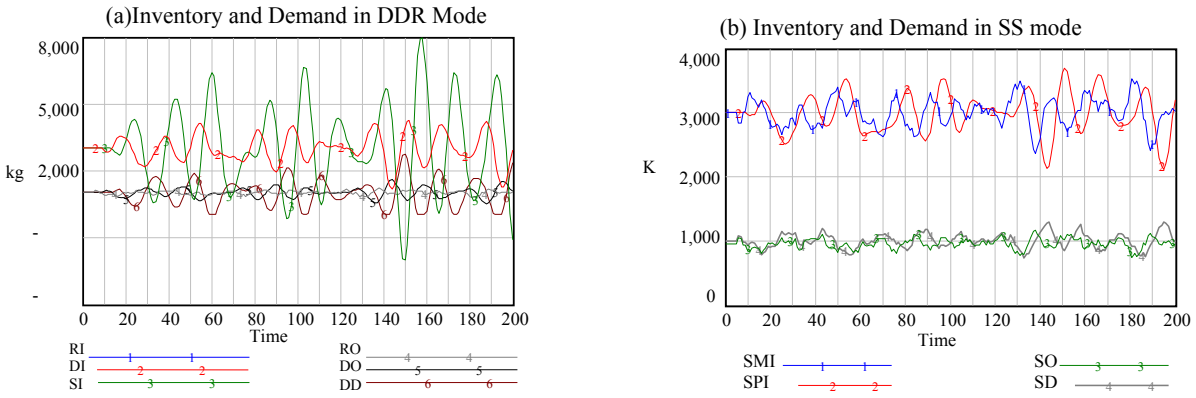

TABLE IV. CHANGES IN INVENTORY LEVEL AND DEMAND RESPONSE BY MODE OF AFSC

DDR Mode			SS Mode		
Retailer demand order	Mean	999.3832	Supermarket demand order	Mean	999.3832
	SD	78.9200		SD	78.9200
Retailer inventory	Mean	2995.8	Supermarket inventory	Mean	2995.8
	SD	224.0098		SD	224.0098
	BE	0.9396		BE	0.9396
Distributor demand order	Mean	1003.9	Supplier demand order	Mean	1002.1
	SD	210.9395		SD	114.4828
Distributor inventory	Mean	2976.6	Supplier inventory	Mean	2985.1
	SD	642.3820		SD	313.6183
	BE	2.5139		BE	1.3630
Dealer demand order	Mean	1009.7	Customer demand	Mean	999.6954
	SD	296.4322		SD	83.9932
Dealer inventory	Mean	3063.5	Note: SD - Standard Deviation BE - Bull-whip Effect		
	SD	1920.9			
	BE	3.5293			

V. CONCLUSION

This study aim to analyze the agri-food supply chain inventory based on system dynamics theory and modeling method. Two main modes are presented and compared. Simulation shows agri-food supply chain with SS mode has lower inventory level, less inventory fluctuation and bull-whip effect dereased. In this more effiecient and effective mode, agri-food supply chain shows better market adaptabiliy and quick response, and gains comparative advantage with traditional DDR mode. System dynamics, to some degree, provide an effective method to analyze the complicated dynamics of supply and demand process of agri-food chain. Admittedly, this study has limitations that we merely consider the relationship of inventory and order, and fail to discuss the implication of order processing time to inventory level. Also, other impacting factors would play some roles. These need to study further later.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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