CSCanada
Management Science and Engineering
Vol. 10, No. 4, 2016, pp. 87-92
DOI:10.3968/8866

ISSN 1913-0341 [Print]
ISSN 1913-035X [Online]
www.cscanada.net
www.cscanada.org

Simulation Research on Supply Chain Carbon Emission Model With SD

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Received 14 July 2016; accepted 5 October 2016
Published online 26 December 2016

Abstract

In this paper, a three-level supply chain model was established based on the theory of system dynamics, which composed of supplier, wholesaler and retailer. The effect of production delay and expected inventory to the total cost of the supply chain and carbon emissions has analyzed by the simulation model. The results show that the three-lever supply chain system was affected by the bullwhip effect in the emission model. As the production delay time increased, the inventory volatility of the supplier and the total emission of supply chain increased, but the total cost of supply chain increased first then decreased. With the increased of the expected inventory duration time, the carbon emissions of each member increased, and the similar variation trend achieved for the total cost of the supply chain. The minimum of the expected inventory duration time was profitable for supply chain, but not for every member. Finally, the expected inventory duration time was divided into three levels based on the expected stocking duration. The results indicated that specific combination of production delay time and expected stock duration determined by the credits of carbon emission.

Key words: Compulsory carbon emissions; System dynamics; Bullwhip effect; Three-level supply chain

Lü, C. C., & Long, X. J. (2016). Simulation Research on Supply Chain Carbon Emission Model With SD. *Management Science and Engineering*, *10*(4), 87-92. Available from: URL: http://www.cscanada.net/index.php/mse/article/view/8866
DOI: http://dx.doi.org/10.3968/8866

INTRODUCTION

Nowadays, with the development of low-carbon economy, the policy of carbon supply chain obtained more and more attention. At the same time, some scholars have paid more attention on the issue of supply chain emission reduction, Benjaafar et al. (2013) add some carbon emission factors into a simple supply chain system study, which comes to a lot of meaningful management inspiration. Hua et al. (2011) build the EOQ model to discuss the carbon trading prices, and study the impact of carbon credits on inventory volatility. Du et al. (2013) study the two-level supply chain composed of a single carbon emission right supplier and a single emission-dependent enterprise under the cap-and-trade mechanism, study the effect of carbon emission limit on enterprise decision under the single-period stochastic demand, The development of low-carbon economy is the major issue and challenge for the development of each country (Kroes, 2012). There is huge practical significance to study the impact of carbon emission policy on the supply chain.

However, few literatures pay attention to carbon emissions of supply chain with system dynamics method. Quantitative analysis only focus on two-lever supply chain, rare research on the carbon emissions policy of three-lever supply chain. Nevertheless, supply chain system is generally multi-level complex in real systems, there is an objective bullwhip effect, and bullwhip effect was resulted by the maximization of self-interest. In this paper, we consider the expected inventory duration and production delay time, analyzed the influence of inventory cost on each member through sensitivity analysis, selecting the appropriate variable size to reduce of bullwhip effect as possible, and further analyze the carbon emissions of supply chain. Finally, the influence of different carbon emission credits on the three-level supply chain and its members is analyzed.

1. RESEARCH OBJECTS AND HYPOTHESIS

The supply chain system consists of a supplier, a wholesaler and a retailer. The supplier arranges the production according to the wholesaler's demand and its forecast. The retailer orders the product from the wholesaler according to the customer's demand and the forecast. The whole system is a pull-type supply chain system. Some basic assumptions are made:

(a) The wholesalers and retailers are using a fixed-cycle bulk ordering strategy;

(b) The supply chain logistics can only flow from the supplier to the wholesalers, wholesalers to retailers, retailers flow to customers, there is no reverse logistics;

(c) The suppliers, wholesalers and retailers were allowed out of stock, and the costs of out of stock were not considered;

(d) The suppliers, wholesalers and retailers are independent of each other at decision-making, there is no information sharing mechanism, and they are economic people.

2. LOW-CARBON POLICY UNDER THE MANDATORY EMISSION MODEL

In this work, the mandatory carbon emission policy was imported, and a supply chain simulation model based on the system dynamics was established. The relationship and trend of the model variables was analyzed, and the impact of the carbon emission policy on the supply chain was determined. There are two main sources of carbon emissions by producers: Production and inventory. Emissions from the production process mainly account for the carbon emissions of the products during the production process, while the carbon emissions during the inventory period refer to the energy carbon emissions consumed in the inventory process. Production carbon emissions were related to production rates and production times, inventory levels and inventory time directly influenced the carbon emissions during the inventory period, and carbon emissions from wholesalers and retailers are similar.

Under the mandatory emission policy, the carbon emission limit of enterprise has a strict limit, the production can based on the actual amount of carbon emissions to arrange, once more than carbon emissions limiting value, the enterprises will punished to halt production. Therefore, the model with mandatory emission conditions added emissions constraints.

2.1 VENSIM Moldel Estabilishing

Considering the complexity of the model, some simplification expression was introduced for some specific descriptions, where *s* refer to the supplier, *w* refer to the wholesaler, *r* refer to the retailer, *R* refer to the rate, *s* refer to the inventory, *c* refer to the cost, *ce* refer to the amount of carbon emission. The main variable parameters meaning is as follows:

Ss: supplier inventory; *ro*: retailer orders; *ws*: wholesalers inventory; *rfq*: retailers expected sales; *rs*: retailer inventory; *Res*: Retailer Expected Stock; *Rsd*: Supplier Shipment Rate; *tes*: Expected Stock Duration; *Rwd*: Wholesaler Shipment Rate; *Scsp*: Supplier Production Cost Accumulated Rate; *Rsp*: Wholesaler Production Rate; *Tcsp*: Supplier Total Production Cost; *mr / u*: Unit Market Demand; *Scss:* Supplier Inventory Cost Accumulated Rate; *pd*: Production Delay; *Tcs*: Total Supplier Cost; *sp*: Supplier Yield; *Tcsc*: total cost of supply chain; *ses*: supplier expected inventory; *pce / u*: unit production of carbon emissions; *pc / u*: unit cost of production; *Spce*: production carbon emissions cumulative rate; *sfq*: suppliers expected sales; *css / u*: supplier unit inventory costs; *wes*: wholesalers expected inventory; *Tssce*: suppliers total inventory carbon emissions; *wo*: wholesalers ordered *Sssce*: suppliers inventory carbon emissions Cumulative rate *Wfq*: wholesaler expected sales volume; *Tsce*: total supplier carbon emissions; *t*1: goods transport delay time; *t*2: inventory adjustment period; *t*3: shift period; *Tpce*: total production of carbon emissions

The relationship between the main equations in the model is as follows:

FINAL TIME=100; INITIAL TIME=0; *rfq*=SMOOTH(*mr*/*u*, *t*3); TIME STEP=1;
mr/*u*=1000+IF THEN ELSE(Time>4, RANDOM NORMAL(-200, 200 , 0 , 100 , 10) , 0);
rs=*tes*×*rfq*; *rs*=INTEG(*Rwd*- *mr*/*u*, 3000); *wo*=MAX(0, *rfq*+(*res*-*rs*)/*t*2); *wfq*=SMOOTH(*Rwd*, *t*3),
Rwd=DELAY3(*min*(*ro*,*ws*),*t*1); *ws*=INTEG(*Rsd*-*Rwd*, 3000); *wes*=*tes*×*wfq*;
wo=MAX(0, *wfq*+(*wes*-*ws*)/*t*2); *Rsd*=DELAY3(min(*wo*,*ss*), *t*1); *Scsp*=*pc*/*u*×*sp*; *Scss*=*css*/*u*×*ss*;
Tcs=*Tcsp*+*Tcss*; *Scws*=*cws*/*u*×*ws*; *Tcwo*= INTEG(*Scwo*, 0);
Scwo=*cwo*/*u*×PULSE TRAIN(0, 1, *Tw*, 100); *Tcm*=*Tcwo*+*Tcws*; *Scrs*=*crs*/*u*×*rs*;
Scro=*cro*/*u*×PULSE TRAIN(0, 1, *Tr*, 100); *Spce*=*pce*/*u*×Rsp; *Sssce*=*ss*×*sce*/*u*;
Tsce=*Tpce*+*Tssce*; *Swoce*=*woce*/*u*×PULSE TRAIN(0, 1, *Tw*, 100); *Swsce*=*ws*×*sce*/*u*;
Twce=*Twoce*+*Twsce*; *Sroce*=*roce*/*u*×PULSE TRAIN(0, 1, *Tr*, 100); *Troce*= INTEG(*Sroce*, 0);
Srsce=*rs*×*sce*/*u*; *Trsce*= INTEG(*Srsce*, 0); *Trce*=*Troce*+*Trsce*; SAVEPER=TIME STEP;

Figure 1 shows the established model with system dynamics simulation software Vensim Ple:

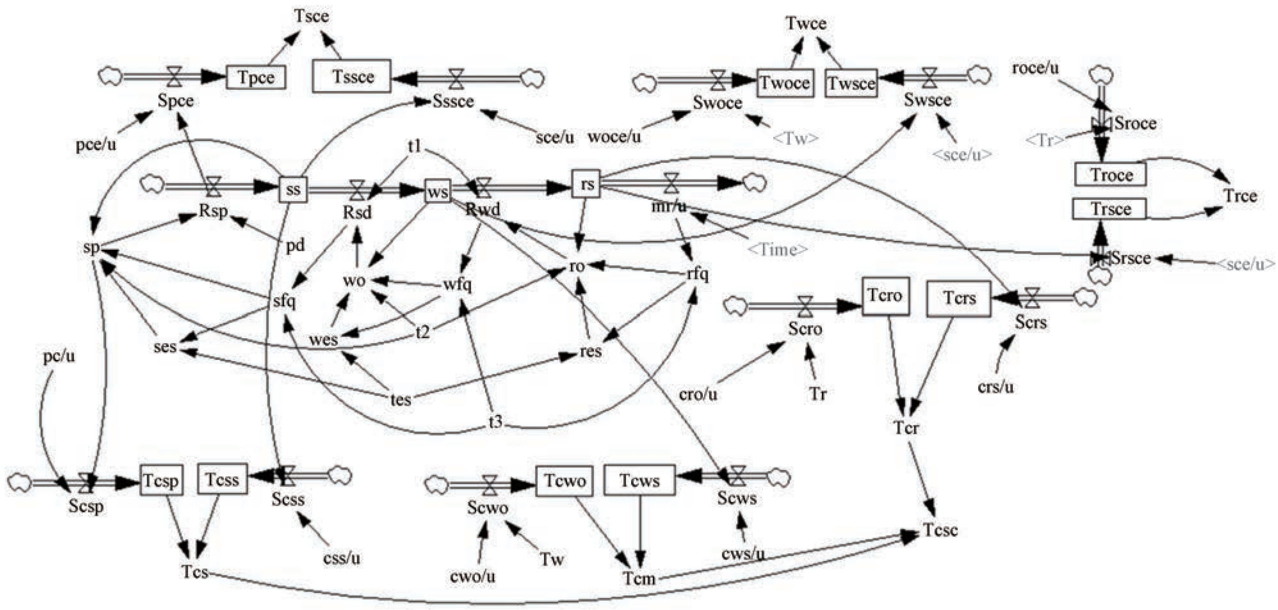

Figure 1
Simulation Model Under Compulsory Policy

2.2 Model Validation

First, the fitness for model structure was tested. The three-lever supply chain model of supplier, wholesaler and retailer is built on the basis of comprehensive investigation and reference mature model. The structure and equation of the system are accordance with the actual system situation. The setting of some variables is based on the actual operation results of the supply chain. In addition, some variables are obtained according to the expert method, and the model passed the dimensional consistency test. All the results indicated that the model structure is desirable.

The consistency of the model and the actual system were also demonstrated. In the model, the production delay time is kept constant. As the expected stock duration increases, the inventory of each member increases, and the upstream increase is much greater than the downstream increase. When the inventory duration increased to a certain extent, the supplier's inventory change is greater. On the contrary, the inventory duration maintain at the same lever, and the production delay time increased, the situation of out of stock would appeare, on the other hand, the peaks and cycles were significantly increased. The final production delay time of simulation was large, and the final inventory was also the largest one. The results show that the production delay will enlarge the bullwhip effect. These conclusions were conformed to the actual situation.

2.3 Sensitivity Analysis

2.3.1 Cost Analysis

The costs of suppliers are mainly composed of production and inventory costs. The production costs grow linearly over time, and other related costs are similarly defined. Figure 2 to Figure 4 shows the cost curves for each member.

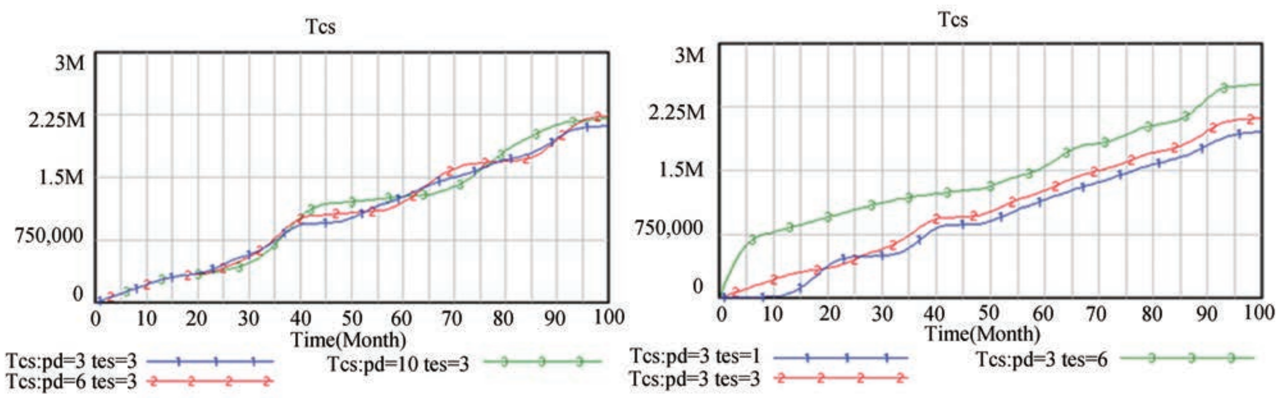

Figure 2
Cost Variance of Supplier

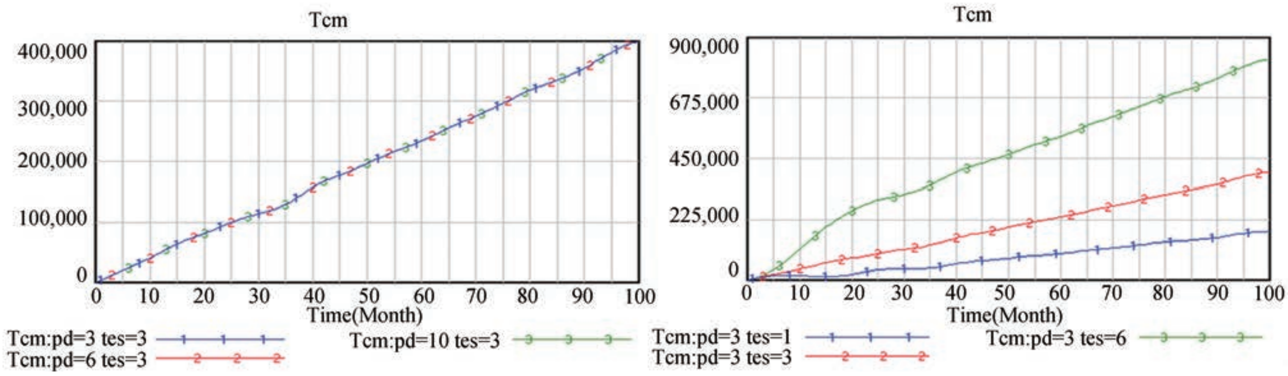

Figure 3
Cost Variance of Wholesalers

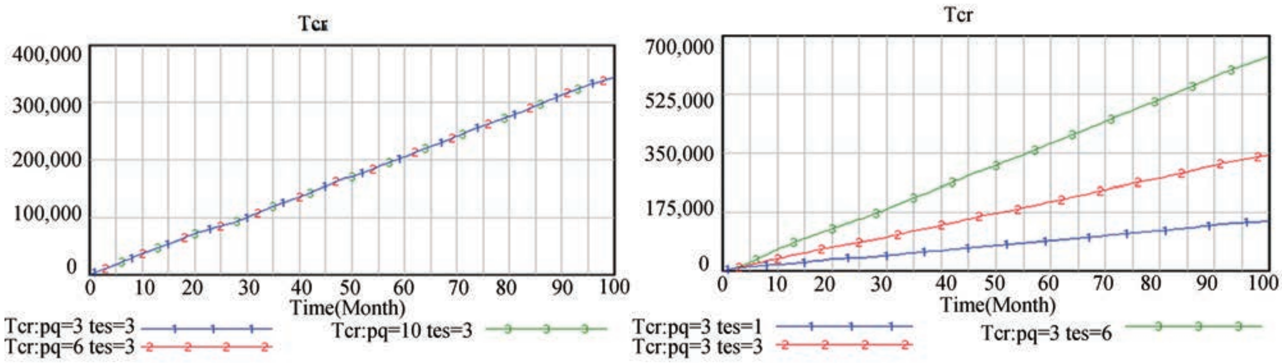

Figure 4
Cost Variance of Retailers

As can be seen from Figures 2-4, when the production delay time was constant, with the increase of inventory duration, the cost of each members was increased, and the increase rate was also increased. When the expected stock duration from 3 to 6, the total cost of suppliers actually turned four times, the reason mainly due to the increase of inventories. When the inventory duration unchanged, the production delay increased, exacerbated the total cost fluctuations in the supplier. At the end of simulation, the total cost increased first and then decreased, but still exceeds the original total cost, while the total cost of the wholesaler and retailer does not change.

The total cost of the supply chain includes the cost of suppliers, wholesalers and retailers. As can be seen in Figure 5, the production delay time is mainly due to the fluctuation and the impact on the inventory, so the impact on the total cost is not significant. The impact of inventory duration on the supplier is more obvious, combined with the above analysis should make the inventory time was less than 3. With the method of "trial and error method", the expected inventory time is 1 or less than 1, the total cost of the supply chain is the same and the lowest.

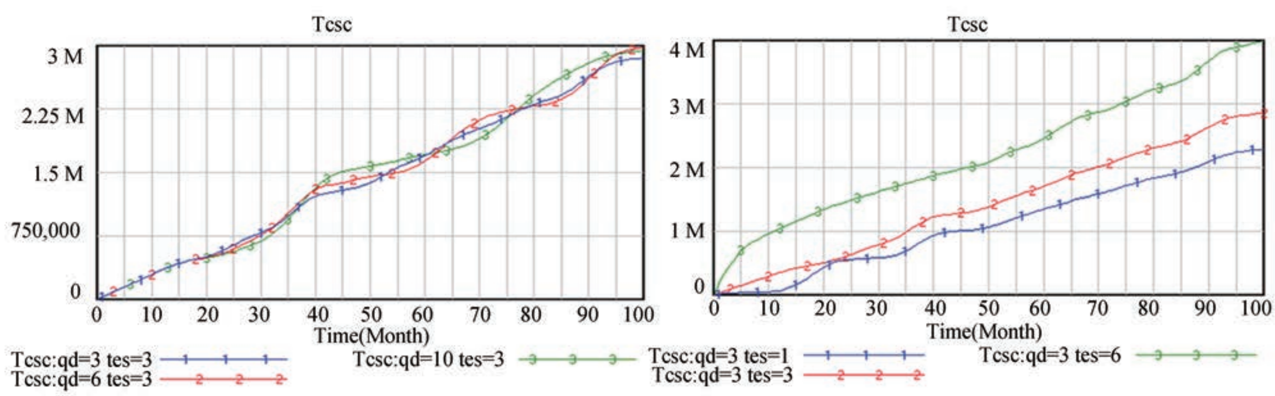

Figure 5
Total Cost Variance of Supply Chain

2.3.2 Carbon Emissions Analysis

According to the above basic model analysis, when the expected inventory duration value as 1 was the optimal for the entire supply chain and the cost of the members. Figure 6 shows that each member's carbon emissions were reduced when the expected inventory duration was changed from 3 to 1. Figure 7 indicated that the carbon emissions size relationship of suppliers and wholesalers has changed. When the inventory duration was 3, the carbon emissions of suppliers, wholesalers and retailers are 132,751, 129,920, 79,531 at the end of the simulation, respectively, and the largest emitter is the supplier, which was 2,831 more than the wholesaler. And when the inventory duration was 1, the suppliers, wholesalers and retailers of carbon emissions were 106,099, 108,213, 59,848, respectively, which was the largest emissions for the wholesalers, and more than the supplier of 2,114 carbon emissions. When the inventory duration was 1, the supplier appeared out of stock, but also allows out of stock for suppliers to win more flexible production opportunities, resulted in the large *t* carbon emissions of wholesalers, that was not conducive to the wholesale business of active orders. Therefore, the selection of inventory duration as 1 was not relatively favorable for all the participants.

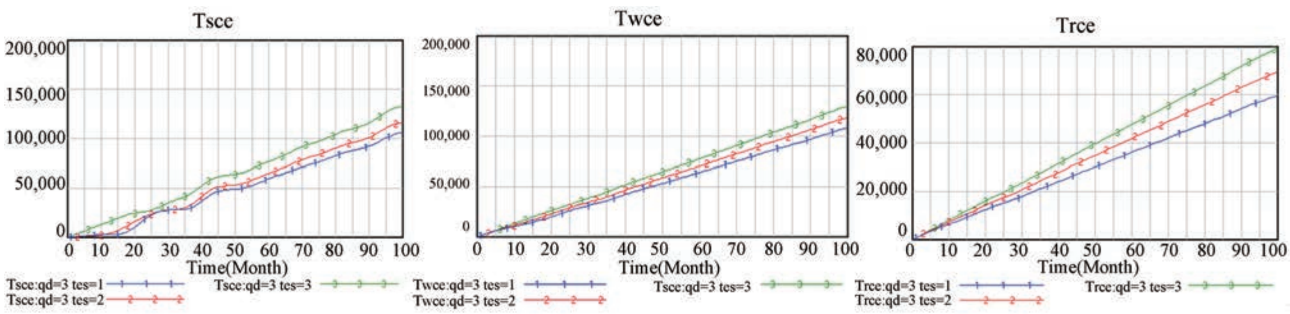

Figure 6
Carbon Emissions for Each Members When Stock Duration From 3 to 1

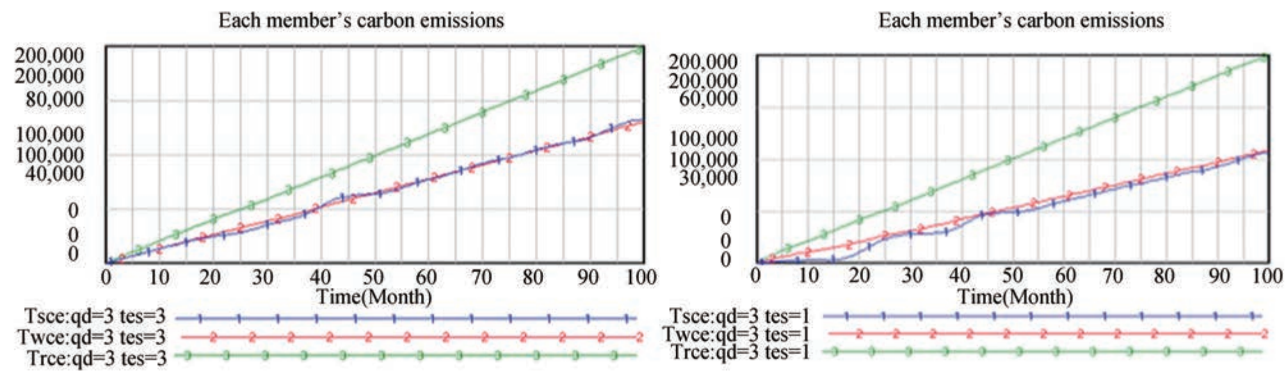

Figure 7
Comparisons of Carbon Emissions From Members

3. MODEL DECISION

The retailer is in the most downstream, fluctuations will not be too large, the situation of carbon excess need not take into consideration. In this paper, different combinations of carbon credits are set up for suppliers and wholesalers. Software simulation can be used to determine the combination of inventory duration and production delay time under different emission limits. At the period of decision, we divided the inventory duration into three levels, based on the total cost of the supply chain, and summarized in Table 1. As can be seen in Table 1, the combination of (0,1) indicated that the supplier's carbon emissions do not exceed the quota and the wholesaler's carbon emissions exceed the quota.

It can be seen that the optimal decision of each level was when the production delay time was 3. The combination (107000, 109000) and (120000, 109000) were the optimal results, in which the expected inventory duration of 1, the production delay time of 3. The results indicated that the supplier's carbon emissions are not necessarily greater than the wholesaler, the optimal conditions for the supply chain to achieve may be sacrificing the supplier's carbon credits.

Table 1
Costs and Carbon Emissions for Different Carbon Credits

Carbon credits	Excess or not									Decision		
	(1,3)	(1,10)	(1,6)	(2,3)	(2,10)	(2,6)	(3,3)	(3,10)	(3,6)	Optimal	emission	Cost
(107000,108000)	(0,1)	(1,1)	(1,1)									
(107000,109000)	(0,0)	(1,0)	(1,0)							(1,3)	214,312	2,285,920
(120000,109000)	(0,0)	(0,0)	(0,0)							(1,3)	214,312	2,285,920
(117000,118000)				(0,1)	(1,1)	(1,1)						
(119000,119000)				(0,0)	(1,0)	(0,0)				(2,3)	234,906	2,577,470
(122000,119000)				(0,0)	(0,0)	(0,0)				(2,3)	234,906	
(135000,128000)							(0,1)	(1,1)	(1,1)			
(140000,130000)							(0,0)	(1,0)	(0,0)	(3,3)	26,2671	2,859,520
(147000,130000)							(0,0)	(0,0)	(0,0)	(3,3)	262,671	2,859,520

CONCLUSION

In this paper, we use the software of VENSIM to build the system dynamics model, and then analyze the impacts of production delays and expected duration of the inventory in the supply chain of all members. The results show that: (a) According to the forced carbon emission model, the three-level supply chain system is affected by the bullwhip effect. As the production delay time increases, the supplier's inventory fluctuation will increase and the total supply chain will increase too. (b) As the expected inventory duration increases, each member's carbon emissions increase, and the total cost of the supply chain increases to a similar degree, although the minimum inventory duration is favorable for the whole supply chain, but not for each member relatively. Finally, the expected duration of the stock is divided into three levels of different levels of emissions to show that different parameters should have to be considered, in order to make the members of the carbon emissions to a minimum, if they only consider their own interests, not only carbon emissions will be constrained, the overall efficiency of the supply chain will be reduced. However, due to the complex structure of the supply chain ordering system, the parameter setting is simplified and the out-of-stock cost is not considered in the study. And other carbon emission policies will be considered for further study.

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