OmniaScience

Journal of Industrial Engineering and Management
JIEM, 2015 – 8(3): 963-980 – Online ISSN: 2013-0953 – Print ISSN: 2013-8423
http://dx.doi.org/10.3926/jiem.1444

The Simulation and Optimization Research on Manufacturing Enterprise's Supply Chain Process from the Perspective of Social Network

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Received: March 2015
Accepted: June 2015

Abstract:

Purpose: By studying the case of a Changsha engineering machinery manufacturing firm, this paper aims to find out the optimization tactics to reduce enterprise's logistics operational cost.

Design/methodology/approach: This paper builds the structure model of manufacturing enterprise's logistics operational costs from the perspective of social firm network and simulates the model based on system dynamics.

Findings: It concludes that applying system dynamics in the research of manufacturing enterprise's logistics cost control can better reflect the relationship of factors in the system. And the case firm can optimize the logistics costs by implement joint distribution.

Research limitations/implications: This study still lacks comprehensive consideration about the variables quantities and quantitative of the control factors. In the future, we should strengthen the collection of data and information about the engineering manufacturing firms and improve the logistics operational cost model.

Practical implications: This study puts forward some optimization tactics to reduce enterprise's logistics operational cost. And it is of great significance for enterprise's supply chain management optimization and logistics cost control.

Originality/value: Differing from the existing literatures, this paper builds the structure model of manufacturing enterprise's logistics operational costs from the perspective of social firm network and simulates the model based on system dynamics.

Keywords: system dynamics, logistics operational cost, supply chain management, simulation

1. Introduction

Social firm network is the sum of the dynamic interactions among various entities—whether individuals or organizations. Firms interact to obtain competitive advantages. A network is not a one-time deal but a stable and lasting relationship. Logistics cost is the monetary form of materialized and direct labor cost in the process of products' spatial displacement. The costs associated with logistics activities normally consist of the following components: transportation, warehousing, order processing/customer service, administration, and inventory holding.

Along with the fast development of economics and technology, social firm network plays a more critical role in enterprise's competitions and cost control. So Manufacturing enterprise's logistics system becomes more complicated.

Most existing literatures study logistics cost control by using Mathematical model and simulation model. As for system feature or quantitative dependency relationship, Mathematical modeling is an approach describing a mathematical structure synoptically or approximately with mathematical words. Mathematical modeling in logistics cost mainly includes linear model, DEA model, nonlinear mixed-integer programming model, Nash equilibrium and multi-objective optimizing stochastic model for non-linear programming. Based on a given set of possible shipping frequencies, Bertazzi, Speranza and Ukovich (1997) discusses the systematic control method for minimizing the transportation and inventory costs. Sheffi, Eskandari and Kourtsopoulos (1988) discusses the transportation mode choice based on total logistic cost and uses a microcomputer model to compare the total logistic cost between a given origin and a given destination point. However this model only takes transportation and inventory costs into consideration. Hu, Shen and Huang (2002) presents a discrete-time linear analytical model in a multi-time-step, multi-type hazardous-waste reverse logistics system for cost-minimization. Huang and Nie (2003) establishes a multi-objective optimizing model to analyze the synthetic logistic cost. Using the traditional inventory mode, VMI inventory mode and an offshoot of the VMI mode. Min, Ko and Ko (2004) proposes a nonlinear mixed-integer programming model and a genetic algorithm to solve the reverse logistics problem involving product returns, which decreases the reverse logistics costs. Through order splitting, Dullaert, Maesb, Vernimmence and Witlox (2004) develops an Evolutionary algorithm to minimize total logistics costs based ono different transport options.

Sun, Peng and Chen (2006) apply DEA model for logistics operational cost control of enterprises, take a logistics operational as a decision making unit to evaluate the efficiency of inputs and outputs. Conclusions show that low efficient activities are eliminated or improved with explicit goals and methods. However, this paper only discusses the cost control theoretically without simulation analysis. Wong, Oudheusden and Cattrysse (2007) use the game theoretic models to analyze the cost allocation problem in the context of repairable spare parts pooling. This study consider two situations: cooperation between members and competition exists. And the cost allocation policy influences the companies in making their inventory decisions. The simulation model is an approach to analyze and quantity the research problem by constructing Mathematical model or systematic model. Logistics cost system of manufacturing enterprises is a discrete event dynamic system. To solve these large, complex and diverse logistics cost control problems, the simulation is an efficient tool. Given uncertain demand, Schuster (1987) uses the Monte Carlo simulation to analyze distribution costs to increase profits by controlling costs. Mason, Ribera, Farris and Kirk (2003) develop a discrete event simulation model based on a multi-product supply chain, which integrates the transportation and inventory to control costs.

Chai (2006) does the modeling and simulation research on the costs of 3PL based on system dynamics. Kara, Rugrungruang and Kaebernick (2007) present a simulation model to study a reverse logistics networks for collecting EOL appliances in the Sydney Metropolitan Area. And this paper also calculates the collection cost. There exists many literature studying on the system dynamics. Shi, Peng, Zhang and Yang (2015) set up a system dynamics model in the supply chain based on the third party cross-docking supply hub mode. By using evolutionary game and SD theory, Mu and Ma (2015) analyze the factors of food supply chain information sharing. However fewer studies exist which applied system dynamics in costs researches. In Sachan, Sahay and Sharma (2004), the system dynamics is used to model the total supply chain cost (TSCC) and but he only considers the number of participants in the supply chain. By comparing the "measured mile" analyses and system dynamics modeling, Eden, Williams and Ackermann (2005) analyze projects costs overruns. Ning and Wang (2004) apply system dynamics to estimate project time and cost. The results help the managers to compute project time and cost. Zhang, Hang and Chen (2007) use system dynamics to study the Bullwhip effect and the relationship between system cost and Bullwhip effect in time-based VMI consolidation replenishment system. Results show that there exists a quadratic convex function between system cost and Bullwhip effect.

This paper build the structure model of manufacturing enterprise's logistics operational costs from the perspective of social firm network and simulates the model based on system dynamics. This rest of paper is organized as follows: Firstly we introduce methods of logistics cost control and the application fields of system dynamics. Secondly we build logistics operational cost model based on system dynamics and also explains the related mechanism. Thirdly we make simulation and optimization research in a Changsha engineering machinery manufacturing firm. Lastly we conclude and put forward the research prospects.

2. Logistics Operational Costs Modeling

As for manufacturing enterprises, the total logistics costs comprise several complex dynamic subsystems. And there is a real lag between system variables. Also the factors influencing logistics operational costs can form a causal loop relationship. So the total logistics cost system is a complex and non-linear feedback system which including several dynamic subsystems. The system dynamics is a valuable and feasible tool to deal with this system. It also acts as a policy lab; we can change the environmental parameters to estimate policy response, which help the policy makers to make effective decisions.

The total logistics costs comprise order costs, transportation costs and inventory costs. From a systemic perspective, we can use system dynamics (SD) to study the total logistics costs as a single system. So this study select the "order-transportation-consumers" process as the object, to analyze the logistics operational costs.

2.1. The model Structure

Manunen (2000) thought that the logistics operational costs in manufacturing enterprises are purchasing costs, transportation costs, warehousing logistics cost (costs in receiving, checking and stacking), inventory costs (including warehousing and shortage costs), out of storage logistics cost(costs in picking, packing and shipping), and sales costs respectively. We classify these six costs into three types, order costs (comprised purchasing and sales costs), inventory costs (including warehousing logistics cost, warehousing and shortage costs) and transportation costs (costs in transport and Cargo damage). In addition, inter-firm network is measured by enterprise network size and contact strength. Enterprise network size is measured by the quantities of upstream and downstream cooperated enterprises. The quantity of upstream and downstream cooperated enterprises with cooperation time more than 2 years describes enterprise network contact strength. This paper divides the research object into three subsystems and they are order processing costs subsystem, total inventory costs subsystem and total transportation costs subsystem. They influence and interact with each other and constitute an organic whole. The model structure is shown in Figure 1.

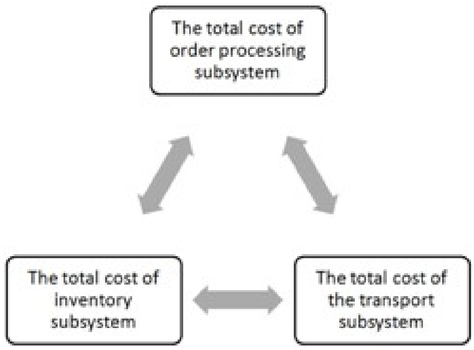

Figure 1. the system of Logistics operation cost

2.2. The Subsystem Analyses

2.2.1. The Order Processing Costs Subsystem

The total order processing costs are influenced by order backlog and unit order cost. The order processing time and cost time of per unit also influence the unit order cost. The processing time is constant. The order processing rate is determined by order backlog and inventory. So the main variables in order costs subsystem are arrival rate, order backlog, original order quantities, processing rate, expected productivity, total expected productivity, delay in normal delivery, processing time, unit order cost, cost per unit time and order processing cost and so on.

2.2.2. The Inventory Costs Subsystem

Gong (2009) presents that the total inventory costs is comprised of storage and out of storage cost, inventory cost and shortage cost. Unit storage and out of storage cost and delivery rate mutually influence the total storage and out of storage cost. Shortage cost is determined by expected inventory, the coefficient of shortage cost and existing inventory. Storage cost is affected by the unit storage cost and existing inventory. However these variables are restricted by other ones. So this paper regards delivery rate, existing inventory, expected inventory, inventory deviation, expected delivery rate, inventory adjustment, shortage, inventory costs, shortage costs, unit inventory cost, unit shortage cost, the coefficient of shortage cost, total inventory costs as main variables.

2.2.3. The Transportation Costs Subsystem

The total transportation cost consists of transportation cost and damage cost. Transportation cost is equal to transport capacity multiplied by shipping rate. Walker (2006) pointed out that shipping rate is affected by transport delay, distance, capacity, real loading rate. Different delay days mean different pipeline inventory costs. The longer the distance, the higher the transportation costs. However given the distance economic law, marginal transportation cost decreases with the increase of the distance (Sterman, 2008). When considering the scale economic law, marginal transportation cost also decreases with the increase of the distance. Because the fixed costs of extraction, delivery and administrative costs decrease with the increase of the capacity. In addition, the higher the real loading rate is, the lower the transportation costs are and the smaller the impact factor of real loading rate is. Main variables in this parts are transport capacity, shipping rate, pipeline inventory rate, transportation costs, cargo damage, cargo damage rate, transport distance, transport delay, real loading rate and so on.

2.3. The Model Building

Through the above analysis, we can build the logistics operational cost model flow chart from the perspective of social firm network (Figure 2). The mathematical relationship between the two variables connected by arrows is artificially constructed and simulated. Model parameters and meanings are shown in Table 1.

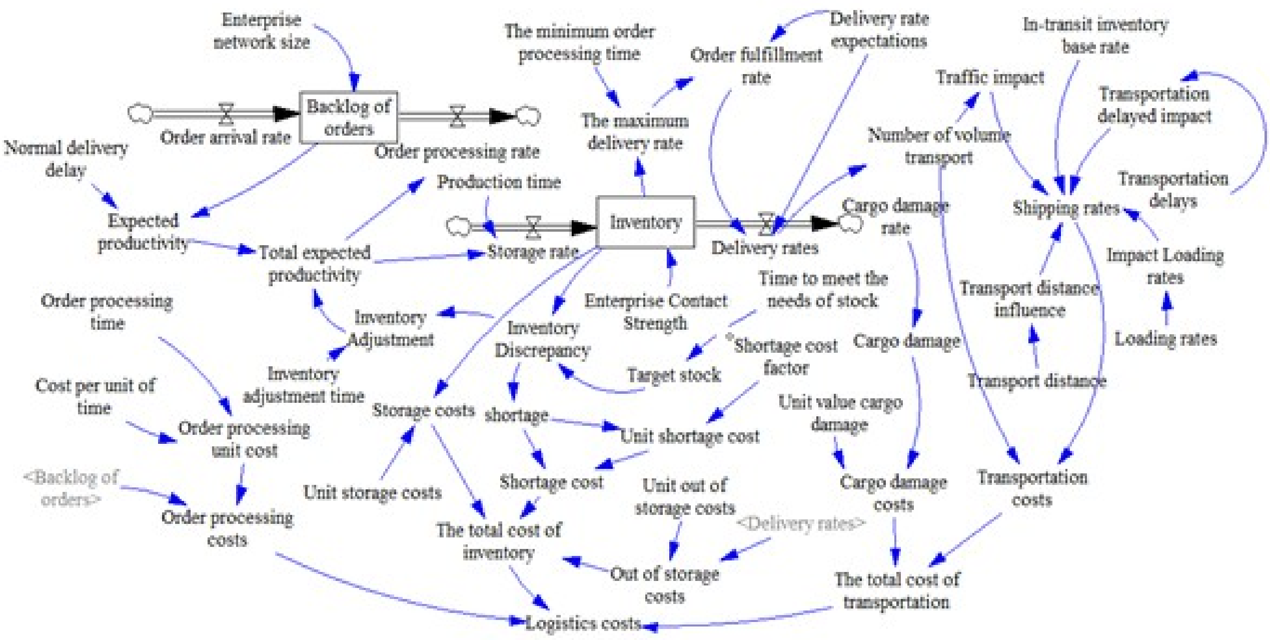

Figure 2. Logistics costs flow chart

Variable	Nature	Variable	Nature	Variable	Nature
Orders arrival rate	Flow	In-transit inventory base rate	Constant	Shortage cost	Auxiliary variables
Storage rate	Flow	Traffic impact	Table Functions	Storage costs	Auxiliary variables
Delivery rates	Flow	Transport distance influence	Table Functions	Out of storage costs	Auxiliary variables
Order processing rate	Flow	Impact of loading rates	Table Functions	The total cost of inventory	Auxiliary variables
Order backlog	Stock	Transportation delayed impact	Table Functions	Traffic	Auxiliary variables
Inventory	Stock	Total expected productivity	Auxiliary variables	Damage to cargo volume	Auxiliary variables
Cost time of per unit	Constant	Order processing time	Auxiliary variables	Cargo damage costs	Auxiliary variables
The minimum order quantity	Constant	Expected productivity	Auxiliary variables	Transport distance	Auxiliary variables
Normal delivery delay	Constant	Order processing unit cost	Auxiliary variables	Loading rates	Auxiliary variables
Inventory adjustment time	Constant	Order processing costs	Auxiliary variables	Transportation delays	Auxiliary variables
The minimum order processing time	Constant	The maximum delivery rate	Auxiliary variables	Shipping rates	Auxiliary variables
Production time	Constant	Order fulfillment rate	Auxiliary variables	Transportation costs	Auxiliary variables
Time to meet the inventory	Constant	Delivery rate expectations	Auxiliary variables	The total transport costs	Auxiliary variables
Shortage cost factor	Constant	Inventory Adjustment	Auxiliary variables	Logistics costs	Auxiliary variables
Unit storage costs	Constant	Inventory Discrepancy	Auxiliary variables	Enterprise Contact Strength	Auxiliary variables
Unit out of storage costs	Constant	Target stock	Auxiliary variables	Enterprise network size	Auxiliary variables
Cargo damage rate	Constant	the amount of Shortages	Auxiliary variables		
Unit cargo damage costs	Constant	Unit shortage cost	Auxiliary variables		

Table 1. Model parameters and meanings

3. The Empirical Analyses

We study the logistics costs, simulate the model and make optimization control in a Changsha engineering machinery manufacturing firm.

3.1. The Main Parameters and Simulation Equation

1) About the order arrival rate. Through the investigation and research, we can obtain the order quantities every month in 2011-2013 (Table 2). It concludes that the order arrival rate obeys Normal distribution approximately based on Matlab analyses.

	1	2	3	4	5	6	7	8	9	10	11	12
2011	521	553	539	559	551	510	559	535	535	550	536	516
2012	559	517	531	558	528	525	530	520	533	551	521	539
2013	519	532	301	516	519	517	525	537	555	399	536	512

Table 2. Monthly orders arrival rates

Apply Kolmogorov-Smirnov test. Procedure is as follows:

x=[521, 553, 539, 559, 551, 510, 559, 535, 535, 550,536,516, 559, 517, 531, 558, 528, 525, 530, 520, 533, 551, 521, 539, 519, 532, 301, 516, 519, 517, 525, 537, 555, 399, 536, 512];

y=zscore[x];

[h, p, k, c]=kstest (y, [], 0.05, 0)

If h=0, then the order arrival rate obeys Normal distribution approximately.

Based on the test, the order arrival rate is: the order arrival rate=RANDOM NORMAL (410, 590, 500, 40, 0).

2) Through the investigation and research, we can obtain the data in February (Table 3).

Variable	Nature	Variable	Nature
Normal delivery delay	4	Unit storage costs	2000
Cost per unit of time	5	Unit cargo damage costs	15000
Initial orders	100	Unit out of storage costs	1000
In-transit inventory base rate	300	The time to meet Inventory	3
Order processing time	5	Shortage cost factor	0.2
The minimum order processing time	3	Production time	3.5
The actual inventory conditions	2	Enterprise network size	5
Cargo damage rate	0.02	Enterprise Contact Strength	3.5

Table 3. Data After survey

3) The relationship between shipping rate and transport capacity, transport distance, transport delay, the real cargo rate is described by Table functions in Figures 3-6, respectively. Figure 3 shows the relationship between shipping rate and transport capacity, the shipping rate first goes up then goes down with the increase of the transport capacity. Figure 4 shows the relationship between shipping rate and transport distance, the change trend is the same as the transport capacity but the change scope is different. As a whole, there exists a decreasing trend between shipping rate and transport delay (as shown in Figure 5). Figure 6 shows an increasing trend between shipping rate and transport the real cargo rate.

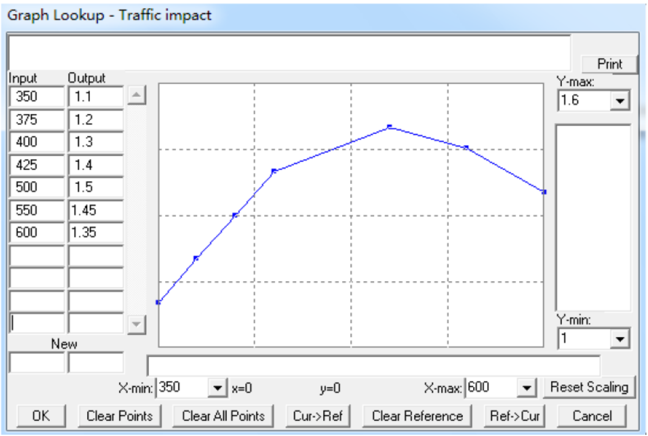

Figure 3. Table function of Transport capacity impact

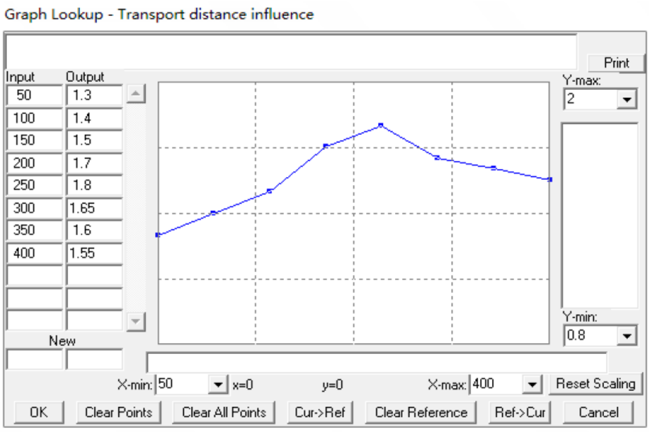

Figure 4. Table function of Transport distance influence

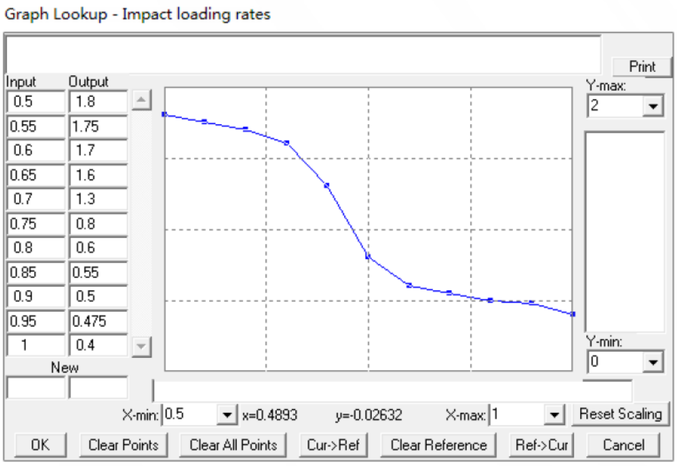

Figure 5. Table function of Transportation delayed impact

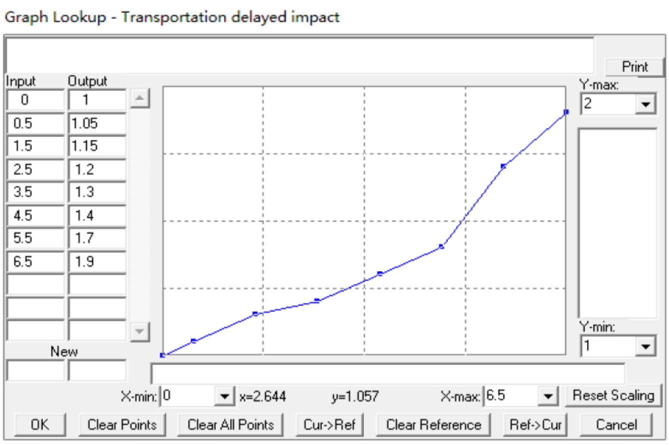

Figure 6. Table function of cargo rate impact

4) About the simulation equation.

The simulation equation of order processing rate is: order processing rate=total expected productivity; total expected productivity=expected productivity + inventory adjustment. So the order processing rate adjusts with the change of inventory and order backlog.

Storage rate=DALAY3 (total expected productivity, production time). Storage rate does not respond to total expected productivity immediately. On the contrary, there exists lag effect. However it will change fast once began to response.

Delivery rate=order operation rate * required delivery rate. Figure 7 shows the simulated order fulfillment rate curve. If order operation rate=1, then it means the real delivery equals to the demanded delivery. If delivery rate decreases to that on the 45º straight line through the origin, it means that DR=MDR; Delivery always equals to the max storage capacity. So the relationship between DR and MDR is always restricted in the bottom right of the two datum lines. When the enterprise has the enough storage, the maximum total delivery rate is rather higher than required delivery rate. Then products shortage will not happen, and order fulfillment rate is 1. When the max total delivery rate decreases, the possibility of shortage will increase and order fulfillment rate will decrease. When the max total delivery rate goes down below required delivery rate, the order fulfillment rate will be less than 1. The decrease of the future supply capacity forces the order fulfillment rate go down, until it deliver the goods according to the maximum delivery rate.

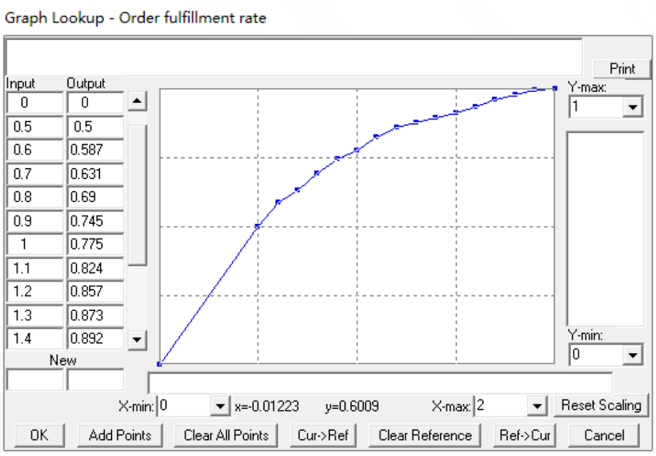

Figure 7. Table function of Order fulfillment rate

3.2. The Model Test

The model test include Mechanical error test, dimensional consistency test, validity test and equation extreme conditions test. This study apply Vensim to do Mechanical error test, dimensional consistency test and validity test. In order to explain the equation extreme conditions test, we use order arrival quantities as an example. When the arrival order is zero, we need to inspect the requirements (Figures 8 and 9).

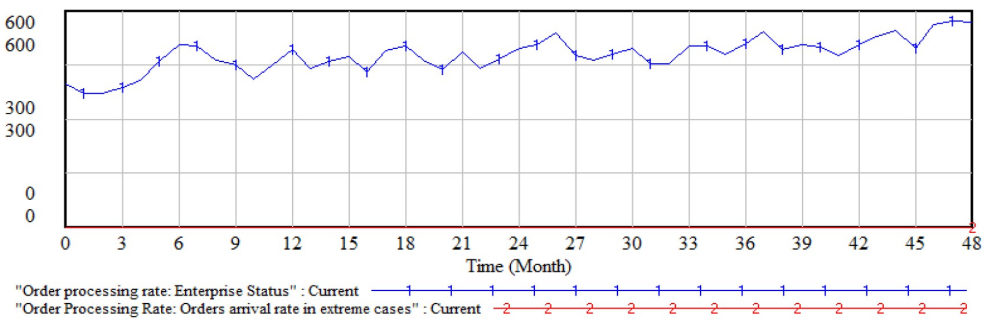

Figure 8. Model tested in extreme conditions

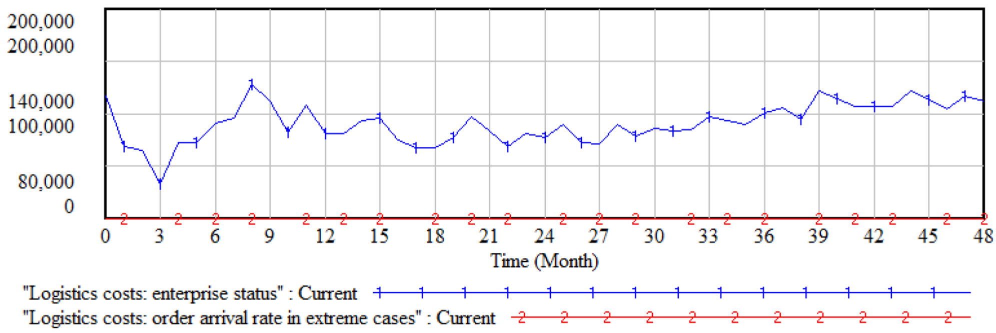

Figure 9. Model tested in extreme conditions

3.3. The Simulation Analysis

We input data into the simulation model, set the simulation time for 4 years. The simulation results are as follows:

1. Order backlog is diversified every month and order processing costs fluctuate (Figure 10). The maximum is 12712 yuan, the minimum is 10000.34 yuan.

2. Total inventory costs include warehousing cost, shortage cost, storage and out of storage cost. The simulation results is shown in Figure 11.

3. Total transportation cost consists of transport cost and shortage cost. As is shown in Figure 12.

4. Logistics operational costs are constituted by order costs, inventory costs and total transportation costs. Figure 13 describes the results.

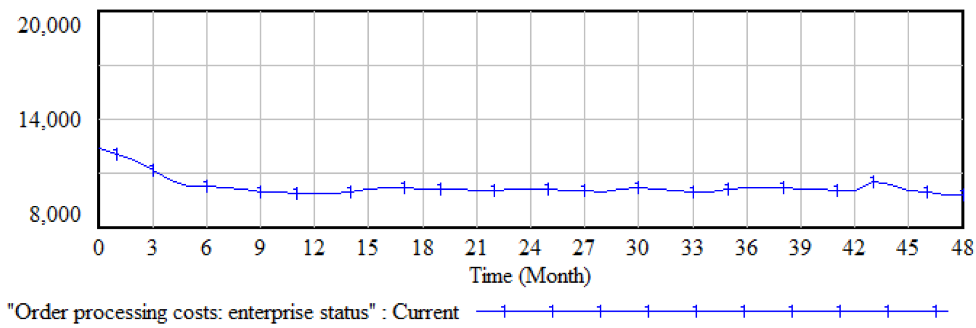

Figure 10. Order processing costs

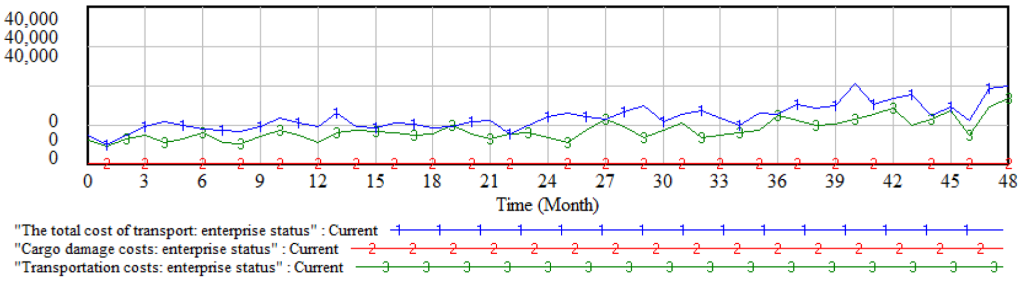

Figure 11. the total cost of inventory

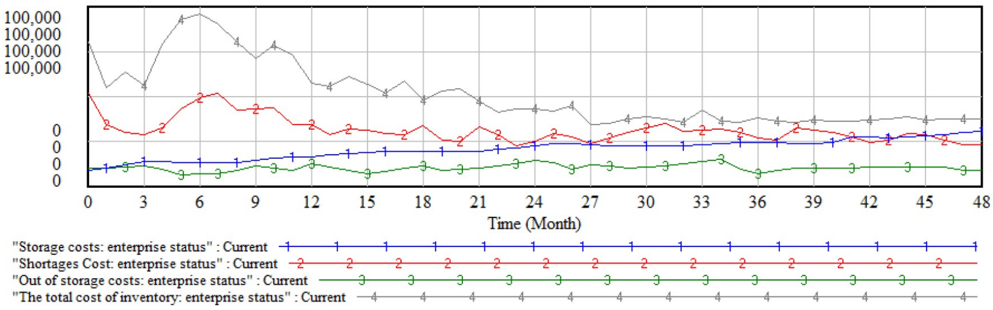

Figure 12. The total cost of transportation

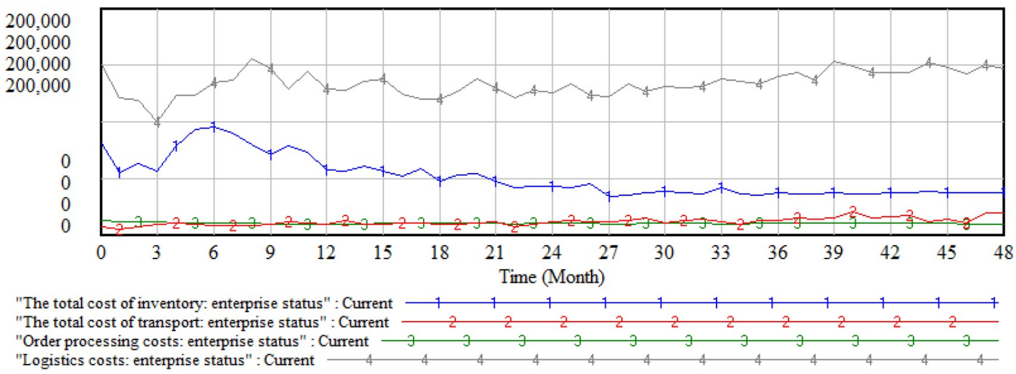

Figure 13. Logistics costs

3.4. The Costs Optimization Control

By using system dynamics to simulate and analyze the logistics cost system, we can find that the total logistics costs comprise of order costs, inventory costs and total transportation costs. In Figure 13, logistics operational costs fluctuate, which results from the fluctuation of inventory costs and total transportation costs. The fluctuation presented in Figure 11 is derived from the shortage costs. Transport costs affect total transportation costs, influenced by shipping rate. It concludes that there are two methods to control the logistics costs. One is to control the inventory costs, the case firm should not only balance the storage to decrease the shortage costs but also reduce the delivery cost per unit, storage cost per unit and the coefficient of the shortage cost; The other is to control the total transportation costs. That is, to control the changes of shipping rate. However the shipping rate is affected by transport distance, transport capacity, transport delay and the real cargo rate. So the Changsha engineering machinery manufacturing firm must focus on the above four factors and reduce their influence.

1. Strategy 1: Improve the time to meet the inventory to decrease shortage costs. Given there exist benefit conflicts between total transportation costs and inventory costs, it is found that the logistics cost reaches to the minimum when the time to meet the inventory is five months (Line 3 in Figure 14-15 and Table 4).

2. Strategy 2: Improve the real cargo rate. The Changsha engineering machinery manufacturing firm can optimize the logistics costs by implement joint distribution.

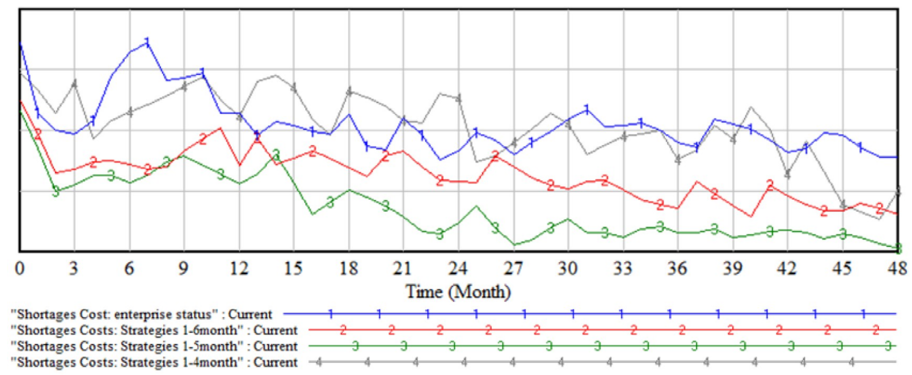

Figure 16. Comparison of the Shortages cost

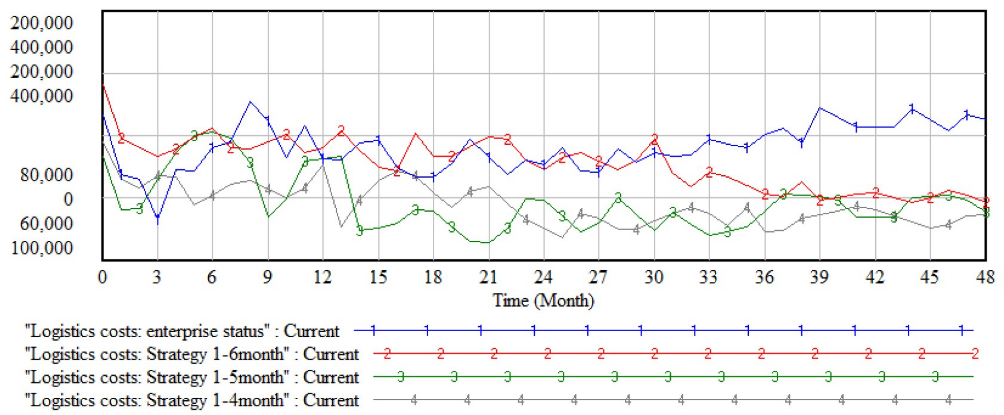

Figure 17. Comparison of the logistics cost

Month	Time to meet the Inventory			Enterprise Status	Month	Time to meet the Inventory			Enterprise Status
	6months	5months	4months			6months	5months	4months	
0	279861	81112	181130	191598	25	160235	42523	50140	56344
1	201378	41322	166138	141356	26	174234	35581	43134	88237
2	179823	42509	150152	131362	27	160345	39616	53193	77500
3	161239	71755	155169	151594	28	145088	50695	40231	66913
4	180393	82188	136196	161444	29	162785	44144	57268	64614
5	209849	92319	99130	91349	30	195686	37156	61307	76027
6	223950	101012	112138	111432	31	146970	42169	68336	88641
7	184739	91228	120275	121716	32	123736	31189	74366	93948
8	170293	61431	128324	141897	33	131345	27205	65361	86768
9	192304	41639	121360	122566	34	121112	33220	87486	69636
10	200781	51915	130399	132637	35	111366	35239	85513	86344
11	160239	82370	146485	122573	36	111519	46259	54110	55465
12	173203	82520	173518	102275	37	121644	52299	50120	56220
13	223834	62681	102570	121652	38	131893	51343	69132	76164
14	160039	33135	79110	171765	39	92311	50395	73156	80640
15	148723	31190	109125	71814	40	102998	46497	79193	91537
16	139841	41212	124150	101578	41	104044	40160	86239	85401
17	212856	46232	139187	131557	42	111046	38203	81222	75435
18	171390	46266	123324	111780	43	105846	38220	73225	64483
19	179348	31308	94360	92868	44	96420	50245	69241	60059
20	189734	24353	115399	123683	45	106796	51266	61249	58893
21	200019	46402	123485	126929	46	117159	52328	62275	61504
22	197832	51445	91518	87116	47	107858	49320	71324	77365
23	168504	50509	76570	66955	48	98622	36301	80360	83755
24	149202	49562	64620	55149					

Table 4. Comparison of the logistics cost

4. Conclusions and Prospects

This paper builds the logistics operational costs model of a Changsha engineering machinery manufacturing firm and simulates the model based on system dynamics. The findings are as follows:

1. The simulation model is feasible and valuable and is able to express the relationship of factors in the system. In the simulation period, the simulation results better reflect the real logistics operational cost in the case firm.

2. The case firm should adjust the time to meet the inventory for five months to reduce the shortage cost. Because the logistics operational cost is lowest when the storage period is five months.

3. The case firm can optimize the logistics costs by implement joint distribution.

The total logistics cost system is a complex and non-linear feedback system including several dynamic subsystems. Although building the logistics operational cost model of order costs, inventory costs and transportation costs, this study still lacks comprehensive consideration about the variables quantities and quantitative of the control factors. In the future, we should strengthen the collection of data and information about the engineering manufacturing firms and improve the logistics operational cost model.

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