Cost simulation and optimization of fresh cold chain logistics enterprises based on SD

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Abstract. In this paper, the system dynamics method is used to construct the structural model of the operating cost of fresh cold chain logistics enterprises considering the carbon emissions, and the simulation experiments are carried out by using Vensim software. The results show that the application of system dynamics in fresh cold chain logistics enterprises cost control can reflect the complex relationship between the various factors within the system better, and obtain the back relationship between carbon emissions and the total cost, the method can provide guidance and reference for cost control of the fresh cold chain logistics enterprises.

1. Introduction

Fresh agricultural products (such as fruits, vegetables, flowers, seafood, etc.) have a special natural attribute-fresh perishable [1]. Therefore, compared with the ordinary logistics, cold chain logistics requirements are relatively high. The corresponding input in management and capital is also greater than the ordinary room temperature logistics, which means the cost is higher than the ordinary logistics. According to the China Food Industry Association, China has wasted about 12 million tons of fruit and 130 million tons of vegetables each year due to cold chain problems, with a total value of $10 billion. At the same time, global warming, high energy consumption, environmental pollution and other issues have made low-carbon economy attention all over the world. Our country also promised that, carbon dioxide emissions per unit GDP in 2020 will decline by 40%~50% than in 2005[2]. These wastes and high carbon emissions are caused by the logistics links of agricultural products in transportation, storage, packaging, loading and unloading, handling, circulation, processing and distribution. Therefore, the research about the operation cost of fresh cold chain logistics enterprise considering carbon emissions based on system dynamics can not only control the fresh cold chain logistics cost from the angle of logistics process in theory and enrich the system of fresh cold chain logistics enterprises, but also reduce the cost and carbon emissions of cold chain logistics enterprises and improve the competitiveness of enterprises in practice.

From the current research literatures, the control methods of logistics cost mainly includes mathematical model method and dynamic modeling simulation and analysis method. A mathematical model is a mathematical structure that describes or refers to the characteristics or quantity dependencies of a certain system of things by mathematical language[3]. The modeling methods of logistics cost include activity-based costing model, system structure model, multi-objective programming model, linear analysis model and nonlinear mixed integer programming model. Wang Xuhui [4] built the fresh agricultural products cold chain logistics decision model adopting the technology according to the Cost and benefit, and emphatically analyzed the effect on upstream and
downstream wholesale prices, retail prices and order volume decisions due to the IOT adoption, thereby reducing the fresh agricultural products cold chain logistics cost. Chen Xichang\[5\] analyzed the major influence factors of cost in agricultural products cold chain logistics activities by the method of AHP, calculated the cost of cold chain logistics based on the activity-based costing, and analyzed the optimization strategy of enterprise cost combining with empirical research. Yang Fang \[6\] constructed the interpretative structural model of fresh agricultural products cold chain logistics system by means of ISM, which reflects the interaction relationship of various elements in logistics network and could provide management coordination mechanisms for reducing logistics costs and improving logistics service ability. Li Susu\[7\] established a mathematical model aiming at the lowest cost of cold chain logistics simultaneously considering the cost of damage and the refrigeration energy consumption cost in the cold chain logistics, which balance the energy consumption cost and cost of damage from the angle of temperature adjustment, so as to achieve the target of the lowest total cost in cold chain system. Bertazzi\[8\] discussed the objective programming model with minimum transportation cost and inventory cost which assumes a single supply point and multiple destinations, and solved the problem using the improved algorithm.

Dynamic simulation is a method that uses mathematical simulation or system model to analyze and measure the research questions \[3\]. Fresh cold chain logistics operation system is a dynamic system of discrete events, and simulation is an effective tool to solve such large, complex and diverse cost control problems. Schuster \[9\] made a model for the process from level 1 warehouse to consumer distribution of production enterprise utilizing large-scale multi-Agent, which is in the case of demand uncertainty and simultaneously takes into account customer service, transportation and warehouse address, order processing and other related elements. Schuster also simulated and analyzed the model by means of the Monte Carlo simulation method, achieving the purpose of reducing costs and enhancing the effectiveness. Zhao Weiyu \[10\] built the enterprise logistics cost system dynamic model using the system dynamics method and made the dynamic simulation; the results reflect preferably the multidimensional time motivation and two-dimensional contradiction and clarify the complex relationship between the factors in the system. Wang Chao \[3\] established a structure model of manufacturing enterprise logistics cost via system dynamics method, and simulated it taking Tianjin handicraft enterprise for example. The results show that increase of loading rate and joint distribution strategy can effectively reduce the cost of logistics enterprises. Gao Qian \[11\] set up a system dynamics model of manufacturing enterprise logistics cost system using AnyLogic software, simulated with the luggage trolley business data of B enterprise, and put forward the optimization strategy of manufacturing enterprise logistics cost control. Chai Tianzi \[12\] construct operation cost model of third party logistics using system dynamics, and carried on the simulation for the trend of transportation and inventory cost in the next three years of the enterprise taking a specific third party logistics as the research object. Kara \[13\] studied the reverse logistics of the final product taking the radius of Sydney as the radiation radius, simulated and calculated the recovery cost of the reverse logistics. Scott \[14\] constructed a discrete event simulation model based on multi product supply chain, which integrated inventory and transportation to reduce cost.

At present, there are not many literatures about the application of system dynamics to cold chain logistics cost. Sachan \[15\] planed the supply chain costs of India grain using the system dynamics principle, but they only considered the number of participants when they analyzed the factors that affect the logistics cost in the supply chain cost. Sun Weiqing \[16\] applied the system dynamics principle to construct the traditional cold chain logistics inventory model and the VMI cold chain logistics inventory model, simulated the two models under different market demands and drewed the relevant conclusions. Yu Shoufei \[17\] established the cold chain inventory control model using the system dynamics and carried on the simulation, which obtains the reason of stock fluctuation and enlargement and proposes the system improvement strategy. The above documents only built the inventory system and simple cost system of cold chain logistics enterprises, most of them are not from the overall point of view. The quantitative research is not enough and the consideration factors are not comprehensive. From the above documents, we can see that system dynamics is a powerful tool to
study the cost system of cold chain logistics enterprises. Therefore, this paper proposes to use system dynamics to simulate and optimize the cost of fresh cold chain logistics enterprises. We can study the fresh cold chain logistics cost system considering the carbon emissions from the overall point of view of the system.

2. Construction of cost model of fresh cold chain logistics enterprises

For fresh cold chain logistics enterprises, there are many complex dynamic subsystems in logistics cost system; variables in the system have stagnation phenomenon; The factors that affect the cost of cold chain logistics enterprises can form a causal loop relationship, so the cost system of fresh cold chain logistics enterprises is a system that contains multiple dynamic subsystems and that is a nonlinear feedback system. The system dynamics can be used to deal with the system effectively and make the research feasible. In addition, the system dynamics provides the dynamic system of cost of fresh cold chain logistics enterprise with a policy laboratory, which could predict a policy reaction under various conditions by changing one of environment parameters in the system, so then it guides the decision makers to better understand the behavior of the system and make a scientific decision[3].

Generally speaking, the cost of cold chain logistics of fresh agricultural products includes transport cost, storage cost, ex-warehouse cost, shortage cost, packaging cost, order processing cost and cargo damage cost. However, considering high carbon emissions of the cold chain logistics enterprises, the "low carbon logistics policy that the national launched and the customer demand for time window for product arrival, this paper converts the carbon emissions that fresh cold chain logistics enterprises generated into carbon emission cost via the carbon tax, and then classifies carbon emission cost as total cost. This paper also classifies the time penalty cost as total cost[18-19]. From the point of view of system dynamics, one or more of these interrelated costs can be analyzed as separate systems. Based on this, this paper chooses the process of “purchasing- storage- sale” of fresh cold chain logistics enterprises as the boundary of the system to analyze the costs and carbon emissions produced by the process of the operation of fresh cold chain logistics enterprises.

2.1 Overall structure of the model

Fresh agricultural products cold chain logistics cost mainly includes the sum of all kinds of logistics activities costs of agricultural products that is involved in the cold chain transportation, storage and sales process, the cost is specifically the sum payment of all human, financial and material resources in the circulation which include transportation, storage, packaging, loading and unloading, circulation and machining, delivery and so on. Based on the literature analysis and the summary, this paper thinks the fresh cold chain logistics cost mainly includes transport cost, in-Warehouse/ex-warehouse cost, order processing cost, packaging cost, cargo damage cost, time penalty cost, carbon emissions cost and shortage cost. These nine costs interact and influence each other to form an organic whole.

2.2 Subsystem-cost analysis

In this paper, the feedback effect between each sub cost item and related factors is analyzed one by one, and then the causal relationship between the factors affecting the cost system of fresh cold chain logistics enterprises is established.

1) Transport cost

Transport cost is calculated by the transport volume and transport rate. Chai Tianzi[12] pointed out transport rates are affected by traffic volume, distance of transportation, delay of transportation and rate of loading.

2) Shortage cost

Storage cost is mainly affected by inventory and unit storage cost. The inventory is also affected by the amount of in-Warehouse and ex-Warehouse.

3) in-Warehouse/ex-Warehouse cost
The in-Warehouse/ex-Warehouse cost of goods mainly includes the in-Warehouse cost and the ex-Warehouse cost, so in-Warehouse/ex-Warehouse cost is mainly affected by the unit cost of in-Warehouse and ex-Warehouse, the amount of in-Warehouse and ex-Warehouse.

4) Order processing cost
Gao Qian[11] believes that the cost of order processing is mainly determined by order quantity and processing cost per order. The order quantity is determined by the order speed, and the processing cost of each order is affected by the unit time cost.

5) Packaging cost
The packaging cost is mainly affected by unit packaging cost and package quantity. When the model is built, the amount of ex-Warehouse is roughly defined as the packing quantity.

6) Cargo damage cost
For fresh agricultural products, the cargo damage cost is mainly affected by the cargo damage quantity and unit cargo damage cost, and the cargo damage quantity contains the transportation cargo damage quantity and the inventory cargo damage quantity. The transportation cargo damage quantity is mainly affected by the traffic volume, cargo damage rate and product freshness, and the inventory cargo damage quantity mainly is affected by inventory and storage deterioration rate.

7) Time penalty cost
In the process of operation and management of fresh cold chain logistics enterprises, customers require a high time for products. Due to the delay in transportation, some penalty costs have been added to the enterprise. Therefore, the time penalty cost is mainly affected by the unit time penalty cost and the transportation delay.

8) Carbon emissions cost
The carbon emissions cost is mainly affected by carbon tax and carbon emissions. Cai Yiping et al [21] pointed out that the carbon footprint of the entire cold chain logistics was calculated as \( C_{\text{cold chain}} = C_{\text{production}} + C_{\text{distribution}} + C_{\text{pre-cooling and storage}} + C_{\text{waste}} + C_{\text{others}} \). Taking into account the system boundary of the model, this paper determines the sum of carbon emissions of the transportation process, storage and the waste goods as the total carbon emissions. The carbon emissions of the transportation process is affected by unit transportation carbon emission, transport volume and transport distance. The carbon emissions of storage is affected by unit storage carbon emission, storage time and cargo volume. The carbon emission of waste goods is affected by unit waste carbon emission and cargo damage quantity.

9) Shortage cost
The shortage cost is mainly affected by shortage coefficient and shortage quantity, while the shortage quantity is mainly determined by inventory and expected inventory. The expected inventory is mainly affected by the order rate that is the market demand.

In conclusion, we can draw the causality diagram of the cost system of the fresh agricultural product cold chain logistics enterprise. As shown in figure 1.
2.3 Model building
Through the further analysis of the fresh cold chain logistics enterprise cost system causality diagram, this paper gets the cost system dynamic model of cold chain logistics enterprise, as shown in figure 2. The mathematical relationships between the two variables connected by each arrow in the diagram are artificially set up and simulated.

The meaning of each parameter in the system flow chart is shown in table 1.
| Variable Name                           | Nature           | Variable Name                           | Nature           |
|----------------------------------------|------------------|----------------------------------------|------------------|
| inventory                              | state variable   | unit waste goods carbon emission       | constant         |
| in-Warehouse quantity                  | rate variable    | transport process carbon emissions     | auxiliary variable|
| ex-Warehouse quantity                  | rate variable    | waste goods carbon emissions           | auxiliary variable|
| procurement transport demand quantity  | auxiliary variable| storage carbon emissions               | auxiliary variable|
| procurement transport cargo damage quantity | auxiliary variable| transport distance influence factor     | auxiliary variable|
| unit storage cost                      | constant         | traffic volume influence factor         | auxiliary variable|
| unit packaging cost                    | constant         | transport delay influence factor        | auxiliary variable|
| transport cargo damage quantity        | auxiliary variable| unit time penalty cost                 | constant         |
| actual purchasing traffic volume       | auxiliary variable| cargo density                          | constant         |
| actual traffic volume                  | auxiliary variable| shortage cost                          | auxiliary variable|
| cargo damage cost                      | auxiliary variable| transport rate                         | auxiliary variable|
| unit cargo damage cost                 | constant         | loading rate                           | auxiliary variable|
| inventory cargo damage quantity        | auxiliary variable| transport delay                        | auxiliary variable|
| storage deterioration                   | auxiliary variable| transport distance                     | auxiliary variable|
| supply transport demand quantity       | auxiliary variable| transport cost                         | auxiliary variable|
| time penalty cost                      | auxiliary variable| packaging cost                         | auxiliary variable|
| market demand                          | auxiliary variable| freshness                              | auxiliary variable|
| expected inventory                     | constant         | cargo damage rate                      | constant         |
| carbon emissions cost                  | auxiliary variable| storage cost                           | auxiliary variable|
| basic transport rate                   | constant         | storage time                           | auxiliary variable|
| order processing cost                  | auxiliary variable| shortage quantity                      | auxiliary variable|
| processing cost per order              | auxiliary variable| cargo density                          | constant         |
| processing time per order              | auxiliary variable| carbon tax                             | constant         |
| loading rate influence factor          | auxiliary variable| shortage coefficient                   | constant         |
| in-Warehouse/ex-Warehouse cost unit    | auxiliary variable| Unit time cost                         | constant         |
| in-Warehouse/ex-Warehouse cost unit    | constant         | order quantity                         | auxiliary variable|
| unit transport process carbon emission | constant         | unit storage carbon emission           | constant         |

3. Simulation study
Cold chain logistics enterprises send fresh agricultural products to the retailer through transport, storage, packaging, loading and unloading, circulation and machining, delivery and other activities, and then the retailer sales to the final consumer. In this process, the sub cost of cold chain logistics
constitutes the total cost of fresh cold chain logistics. Studies have shown that logistics delivery has become one of the important sources of global carbon emissions, while cold chain logistics is a highly energy consuming and high carbon emission business in the logistics industry. Then, what are the nine sub costs that affect the total cost of cold chain logistics firms and what is the ratio of the nine sub costs of the total cost? What are the main factors that affect carbon emissions and how carbon emissions affect total costs? This paper mainly carries on the research on these two problems.

There are a variety of products those can be circulation and machining, such as meat, fruits and vegetables, quick-frozen rice, medicine and so on. Those products all need to keep low temperature in the process of transportation and storage. According to the National Bureau of statistics data, it has also been shown that China's vegetable production has developed from 592 million tons in 2008 to 774 million tons in 2016, which makes the vegetable yield exceed grain yield and become the most productive agricultural products in China. Therefore, it increases consumer demand for fresh produce, and then increases the circulation and machining of fresh agricultural products in the cold chain logistics enterprise [22]. Therefore, this paper chooses the activity process of “purchasing- storing-selling” of tomatoes in cold chain logistics enterprises as an example to make the simulation analysis and optimization the cost of cold chain logistics enterprises.

3.1 Determination of the main parameters and simulation equations of the model

1) Determination of market demand

There are a variety of different demand conditions in the reality supply and demand market of cold chain. It could be that demand will suddenly increase sharply, or show a uniform growth, or suddenly increase sharply in special time and then return to the original level, or fluctuate regularly when it reaches a certain number. In view of the space problem, this paper takes the market demand to reach a certain number of grades, and conducts regular simulation of the system as a case of regular fluctuations.

Through investigation and consultation of relevant literature, the market demand function set by this model is: market demand=600+66*SIN (Time/4). Moreover, the market demand is defined as order quantity in the model.

2) Determination of purchasing transport demand

In the model, considering the purchase and delivery of agricultural products, the traffic volume is set up as the sum of the purchasing transport demand and the supply transportation demand. Among them, the supply transportation demand is determined by the ex-Warehouse quantity. Generally speaking, the purchasing transport demand should be affected by inventory and order quantity at the same time, but in order to reduce the complexity of the model, the purchasing transport demand is considered separately. Through literature summary, it is known that the purchase order is generally balanced. So the purchasing transport demand function set in this paper is: purchasing transport demand=600+STEP (100, 50).

3) Determination of related parameters

After investigation and reading of generous literature, this paper determines the relevant parameter input, as shown in table 2.

| Table.2 Parameters Input Value |
|--------------------------------|
| parameter | input value | parameter | input value |
| initial inventory | 1000(t) | unit cargo damage cost | 100(yuan/t) |
| unit in-Warehouse/out-Warehouse cost | 95(yuan/t) | basic transport rate | 188(yuan/t) |
| unit time cost | 25(yuan/h) | unit waste goods carbon emission | 41.21(kg/t) |
| unit storage cost | 228(yuan/t) | unit packaging cost | 50(yuan/t) |
| Shortage coefficient | 0.25 | cargo density | 0.78×10³(kg/m³) |
| unit transport carbon emission | 0.81714(kg/t*km) | Unit storage carbon emission | 0.08604(kg/m³*d) |

4) Determination of the cargo damage rate, freshness and storage deterioration rate
The functions of cargo damage rate, freshness and storage deterioration rate that this paper set respectively are:

- Cargo damage rate = RANDOM UNIFORM (0.01, 0.05, 0)
- Freshness = $e^{-\alpha t}$, $\alpha = 0.05$
- Storage deterioration rate = RAMP ($\alpha \ast \beta \ast \gamma \ast \mathcal{t}$), $\alpha = 0.001, \beta = 1.5, \gamma = 3$

5) The table functions of influence factor of transport volume, transportation distance, transportation delay factor and loading rate (estimated value) are shown in figure 3-6.

6) Determination of the main simulation equations

The simulation equation of traffic volume is: traffic volume = purchasing transport demand volume + supply transportation demand volume, supply transportation demand volume = outbound quantity = order quantity = market demand. As a result, the supply transportation demand is adjusted with the change of market demand.

Cargo damage quantity = transport cargo damage quantity + inventory cargo damage quantity, transport cargo damage quantity = actual traffic volume * cargo damage rate * freshness, inventory cargo damage quantity = inventory * storage deterioration rate.

Total carbon emissions = transport process carbon emissions + waste goods carbon emissions + storage carbon emissions; transport process carbon emissions = unit transport carbon emissions * actual transport volume * transport distance, waste goods carbon emissions = unit waste goods carbon emissions * (transport cargo damage quantity + inventory cargo damage quantity), storage carbon emissions = unit storage carbon emissions * cargo volume * storage time.

At the same time, this paper has tested model behavior and the consistency between the model and the actual system through the test of extreme conditions and abnormal behavior, which finds that the change trend of these variables under extreme conditions test and abnormal behavior test is consistent with cost system of fresh cold chain logistics enterprise in reality. Therefore, the cost system dynamic model of fresh cold chain logistics enterprises can realize the real reappearance of dynamic behavior of the system [23].
3.2 Simulation result analysis

The parameters are entered into the model and the simulation period is set from 1 to 60 weeks (the simulation period can be determined by the decision maker's need). The simulation results are as follows:

1) The simulation results of the total fresh cold chain logistics cost and the cold chain logistics cost for 60 weeks are shown in the following figure 7-8.

![Fig. 7 comparison among the costs](image7)

Simulation analysis is carried out using the method of system dynamics for the cost system of fresh agricultural products cold chain logistics enterprises, and then it can be found that the total cost of fresh cold chain logistics enterprises mainly consists of transportation cost, storage cost and ex-Warehouse cost from figure 7 and figure 8. Also, the total fresh cold chain logistics cost shows some volatility, and the irregular fluctuation is mainly due to the fluctuation of transport cost, while the fluctuation of transport cost is mainly caused by irregular fluctuation of transport rate. In addition, the storage cost is closely related to the inventory, and the in-Warehouse/ex-Warehouse cost is closely related to the in-Warehouse/ex-Warehouse quantity. It can be seen from the above analysis that the effective control for the total cost of fresh cold chain logistics mainly includes two aspects. On the one hand, it is to control the transportation cost, which mainly embodies in the control of transport rate. On the other hand, it is to control the storage cost and ex-Warehouse cost, which mainly embodies in the control of the inventory and the condition of in-out stock.

2) The simulation results of total carbon emissions and every sub carbon emissions for 60 weeks are shown in figure 9.

![Fig. 9 comparison among the carbon emissions](image9)

From Figure 9, it can be found that the total carbon emission of fresh cold chain logistics enterprise also shows some volatility, and the volatility is mainly caused by the irregular fluctuation of transport process carbon emissions. While the volatility of transport process carbon emissions is mainly affected by the amount of actual transport quantity. Therefore, it can be concluded that the effective control of
the total carbon emissions of the fresh cold chain logistics enterprises is mainly the control of the carbon emissions during the transportation process that mainly reflects in the control of actual transport quantity.

3.3 Optimal control of carbon emissions and cost

1) Strategy 1: Increasing the amount of periodic purchase. It can reduce the actual traffic volume, thereby, which can reduce the total carbon emissions and ultimately reduce the cost of carbon emissions. Simulation result shows that the carbon emission cost and the total cost of fresh cold chain logistics have the reverse effect. So it makes carbon emissions reduce through increasing the amount of periodic purchase, but which also increases the total cost of fresh cold chain logistics. Therefore, the enterprise should adopt appropriate strategies to minimize carbon emission and total logistics cost, and then find the equilibrium between them. The enterprise cannot consider only one of the items and ignore the amount of the other. The simulation results of actual transport volume, total carbon emissions and total cost of fresh cold and fresh logistics during 60 weeks are as shown in figure 10-12 after adjusting the purchase volume.

![Fig. 10 comparison of actual traffic volume](image1)

![Fig. 11 comparison of total carbon emissions](image2)

![Fig. 12 comparison of total fresh cold chain logistics cost (1)](image3)

2) Strategy 2: Increasing loading rate. Cold chain logistics enterprise can choose appropriate load truck to make the carry goods procurement and distribution according to the inventory and the demand of customer, which can reduce the cost of enterprise and then optimize the cost of fresh agricultural products cold chain logistics. The simulation result of the total cost of fresh cold chain logistics during 60 weeks is shown in figure 13 after adjusting the loading rate.

![Fig. 13 comparison of total fresh cold chain logistics cost](image4)
Fig. 13 comparison of total fresh cold chain logistics cost (2)

The changes in purchasing transport demand volume and loading rate are shown in table 3.

| variable name                | before adjust          | after adjust             |
|------------------------------|------------------------|--------------------------|
| procurement transport demand quantity | 600+STEP (100,50)      | 650+STEP (100,50)        |
| loading rate                 | RANDOM NORMAL(0.6, 0.85, 0.78, 0.01, 0) | RANDOM NORMAL(0.7, 0.85, 0.78, 0.01, 0) |

4. Conclusions

Through the research and analysis of this paper, we can draw the following conclusions:

1) The cost simulation model of the fresh cold chain logistics enterprise is effective and reasonable, and it can express preferably the relationship among various factors within the system. In the simulation period, the simulation results reflect the actual situation of the cost of cold chain logistics enterprises. The theoretical suggestions those are analyzed by the simulation results not only have practical guiding significance for the relevant practice, but also provide a reference for the prediction and decision-making of similar problems.

2) If increasing the periodic purchasing quantity, it can reduce the carbon emissions of enterprises, but it also increases the total cost of cold chain logistics enterprises. Therefore, enterprises can not ignore the relationship between carbon emissions and total cost before making decisions.

3) Fresh cold chain logistics enterprises can improve the loading rate in the transportation by choosing the appropriate freight cars and delivery routes, thus reducing the cost of enterprises.

Because the operation cost system of the fresh cold chain logistics enterprise is a complex system which contains many subsystems. The operation cost system of fresh cold chain logistics enterprises and the nine subsystems have been modeled and studied, but it does not fully take into account the relevant variables in the sub cost system of the model, and the quantification of the controllable factors is still inadequate. In the future, it is necessary to strengthen the collection and arrangement of the fresh cold chain logistics enterprise data, and improve the general factors of the cost of fresh cold chain logistics enterprises, so that the model is more complete and practical.

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