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STUDY ON ROUTE OPTIMIZATION OF COLD CHAIN LOGISTICS OF FRESH FOOD

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ABSTRACT
Take the distribution of the national express refrigerated transport company as a example to verify the basic model of cold chain logistics distribution routes. If the transportation cost and the number of customers are consistent in per unit mileage, the longer service mileage from distribution center to the customers, the greater total transportation cost. Therefore, the total cost of vehicle transport is proportional to service mileage. The greater spoilage costs per product caused by the accumulation of mileage and the lapse of time, the higher total damage costs. The higher unit price, the greater total damage costs of fresh products caused by transport time and car door opening. Hence, the damage cost is proportional to the transport time and the unit price of goods. Divide customer points according to the regions of customer points and the limit load capacity of 11t vehicles based on good road condition, cluster analysis of results, respectively use the standard genetic algorithm and the improved genetic algorithm to calculate under the same control parameters, compare them and obtain the results. The results show that the improved genetic algorithm is superior to the standard genetic algorithm in the calculation of the speed and efficiency.

1. Introduction

Logistics distribution is a set of logistics activities include classifying and allocating goods in the logistics center in accordance with the requirements of the customer orders, and delivering prescribed goods to the consignees promptly. Distribution is the last link of customer service; its position is very prominent. Optimizing logistic distribution routing problem, also called Vehicle Routing Problem (VRP), which is one of the hot topics in the current researches of logistics system. It refers to the proper organization of vehicle routing between the delivery points and the receiving points under some constraint conditions such as customers' quantity demanded for goods, vehicles bearing capacity, shipping time, delivery time and travelled mileage, to achieve the goal of the shortest distance, least cost, delivery on time, used vehicle as less as possible. Many experts at home and abroad have proved that the genetic algorithm (GA) has great advantage in solving the VRP.

2. Materials and methods

2.1. component of Vehicle Routing Problem

The main components of Vehicle Routing Problem include goods, distribution center (or logistics center), customers and vehicles.

(1) Good

The goods is the object of distribution. We can take each demand goods as a batch of individual goods. Each batch of goods includes following properties: name, weight, volume, packaging, required delivery time and place, whether can partial distribution or not(Wang,

2012). The goods in cold chain logistics include the aforementioned processed foods, fresh fruits and vegetables and other agricultural products, as well as a part of drugs and other special products that need refrigerated transport(Montanari, 2008).

(2) Distribution center

Distribution center is engaged in disposing goods which consists of consolidation, processing, picking, allocation and organization of the delivery in order to achieve the modern distribution facilities for supply or sale(Palacio and Nuin, 2009). In a distribution system, distribution centers can appropriately adjust their number according to the distribution network problems (Hoang and Alvarez, 2012). If some distributions have a lot networks and their coverage is quite extensive, we often adopt multilevel distribution center to realize the delivery: the first level distribution center sends goods to the next level distribution center; under multiple two levels distribution centers, the research on how to arrange the distribution between different distribution centers relates to the optimizing distribution problem. (Li and Nien, 2010).

(3) Consumer

Customers can also be referred to users, including the retail stores, consumer point, etc. The number of goods required by a single customer may exceeds or less than the allowable loading capacity of a certain vehicle in a logistics distribution. In the above case, when the total demand for goods exceeds the total transport capacity, we need to deliver goods by several times or several vehicles; when the demand is less than the allowable loading capacity of a vehicle, we should carry out cargo stowage if possible (Wu and Zhao, 2013). The time of goods demanded by a customer is the required delivery time and it can be divided into the following several situations: no time window constraint; required during a specified period of time, namely complete delivery within the time window; have time window constraint, but may not comply if we take given punishment(Lan and Xue, 2013).

(4) Vehicles

Vehicle is the carrier of goods, its attributes include: type, loading capacity, size, purchase price, service life, the maximum stroke of distribution, vehicle parking location before and after the completion of the task, etc(Xu and Gong, 2016). Cold chain vehicle is the main distribution equipment for cold chain logistics system; the allocation of vehicle plays a decisive role in maintaining freshness of fresh food, improving transport efficiency, saving energy and reducing transportation costs; it not only affects the enterprise's economic benefit, but also related to the benefits of the whole society.

In order to play the distribution's role to achieve the distribution efficiency, the distribution process including: formulate a distribution plan, issue the distribution plan, confirm requisite amount according to the distribution plan, distribution points deliver goods to the warehouse, allot goods, packaging, finance department issue a specific task distribution, shipping and deliver, as shown in Figure 1.

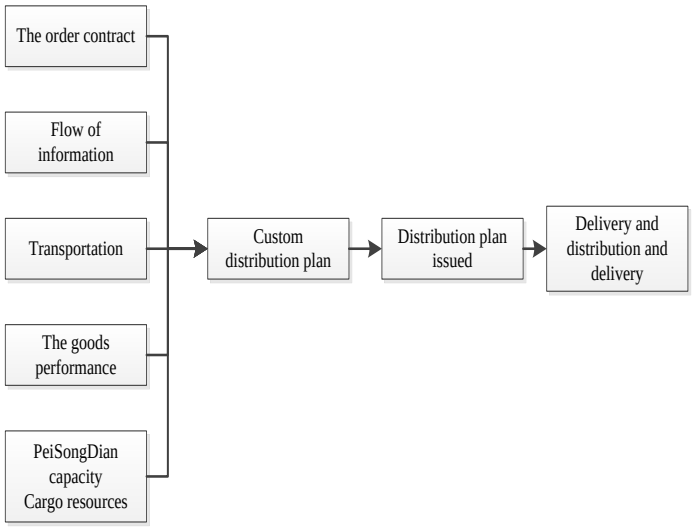

Figure 1. The working process of the vehicle distribution

2.2. Establishment of distribution mode

(1) Hypothesis on distribution problem

Model of cold chain logistics distribution is a distribution model where one DePot to many customers, the type of fresh food in distribution is single, also meets the following conditions:

①One-way flow of goods, that is, pure delivery;

②There are K vehicles, each vehicle has a certain load capacity constraint, but the total capacity of all vehicles is greater than a single customer demand on the transport route;

③Each customer's demand is known, the required goods can only be completed by a vehicle, and all customers have to get service;

④Set distribution centers in the starting point and the end point of each route, that is, all vehicles must complete the task within the specified time and return to the distribution center;

⑤Each customer has a designated service time window; Delivery must be carried out within this time range;

⑥If it belongs to multiple targets, the transportation cost is minimum, the transportation mileage and the total waiting time of all customers is shortest;

⑦The optimal distribution routes between distribution center and the customer, as well as between any two customers have been calculated by the logistics distribution route optimization system;

⑧Do not consider the situation of vehicle congestion, regard the road traffic is smooth, no rush hour.

(2) Establishment of distribution model

The transportation cost of distribution vehicle is comprised of 2 parts, fixed cost and variable cost. The fixed cost is constant, which is not directly related to the number of customers and transportation mileage. Generally, it includes vehicle depreciation expense, ancillary equipment, and fixed assets which is related to transportation, such as the driver's wages. If there are m vehicles, the fixed cost per vehicle is c_k, then the total fixed cost is $\sum_{k=1}^{m} c_k$. The variable cost of distribution vehicles includes fuel consumption, maintenance and other costs; the variable cost of vehicles is proportional to the traveled miles. For the general vehicle transportation costs of distribution, we adopt the formula (1) to calculate.

$$Z1 = \sum_{k=1}^{m} c_k + \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{m} c_{ijk} x_{ijk} \quad (1)$$

s.t.

$$\sum_{i=0}^{n} g_i y_{ik} \le q, k = 1, 2, \cdots, m \quad (2)$$

$$\sum_{k=1}^{m} yik = \begin{cases} 1 & i = 1, 2, \cdots, m \\ m & i = 0 \end{cases} \quad (3)$$

$$\sum_{i=0}^{n} x_{ijk} = y_{jk}, j = 0, 1, \cdots n, ; k = 1, 2, \cdots m \quad (4)$$

$$\sum_{i=0}^{n} x_{ijk} = y_{ik}, \mathrm{i} = 0, 1, \cdots n, \quad (5)$$

$$x_{ijk} = 0 \quad or \quad 1 \quad i, j = 0, 1, \cdots n; k = 1, 2 \cdots, m \quad (6)$$

$$y_{ik} = 0 \quad or \quad 1 \quad i, j = 0, 1, \cdots n; k = 1, 2 \cdots, m \quad (7)$$

(3) The damage cost in the process of delivery

Fresh food belongs to perishable food, there are many factors affecting the spoilage of fresh food. It is assumed that the fresh food can be maintained in fixed temperature in the delivery, then the decay of fresh food in distribution only relate to the delivery time without considering other influencing factors(Lan, 2012). On the other hand, the back door of vehicle will be opened due to customer service; it will increase the addled speed of fresh food. With the different opening frequency and length of time, the quality of fresh food will be affected in varying degrees. So we analyze the fresh food spoilage into two kind situations: One damage is caused by fresh food spoilage due to the accumulation of time in the delivery; the other damage is caused by customer service. When the back door of vehicle is opened, the hot air

from outside flow into and the cold air from inside flow out, which increases the temperature in vehicle, then the damage of goods is caused by rapid decline in quality of fresh products. The two parts of the cost can use formula (8) to calculate.

$$Z_2 = p\sum_{k=1}^{m}\sum_{j=0}^{n}\lambda_{jk}\left(a_1 zi_j + a_2\beta_j\right) \tag{8}$$

When the outside temperature is relatively high, the energy cost of the refrigerator vehicle is also higher; the real-time change of the temperature will affect the energy cost of the refrigerated vehicle during the distribution of fresh products. In the aspect of energy cost calculation, the energy cost in the distribution process is proportional to the temperature difference between the inside and outside of the car. Set the temperature difference between the inside and outside of the car at a given time asΔh (t), a is the energy cost at per temperature difference and per unit time, the total energy cost is:

$$\sum_{k=1}^{m}\left[\int_{t_1}^{t_2} a\Delta h(t)dt\right] \tag{9}$$

Amend the original model based on this one.

(4) The penalty cost when exceed the customer delivery time

$$\begin{aligned} &s0 = 0 \\ &x_{ijk} = 1 \Rightarrow s_i + t_i + t_{ij} = s_j \\ &i, j = 0,1,\cdots n, i \neq j \\ &E \le s_j \le T_j,\ j = 0,1,\cdots, n \\ &t_i = \max\left\{E_i - s_i, 0\right\} \end{aligned} \tag{10}$$

The following can be expressed as the penalty cost of the time window during the distribution of fresh goods:

$$Z_3 = d\sum_{j=0}^{n}\max(E_j - s_j, 0) + e\sum_{j=0}^{n}\max\left(s_j - T_j, 0\right) \tag{11}$$

(5) Optimization model of distribution

For the genetic algorithm, usually the evaluation function is only one. Under the circumstance of uniform target unit and dimension, the multi object model is processed directly by using the linear weighting method, which the simply add several targets into a single objective. Therefore, the optimization model of cold chain logistics distribution is as follows:

$$\begin{aligned} \min Z = &\sum_{k=1}^{m} C_k + \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=0}^{m} c_{ijk}x_{ijk} + p\sum_{k=1}^{m}\lambda_{jk}\left(a_1 z_{ij} + a_2\beta_j\right) + \sum_{k=1}^{m}\left[\int_{x_1}^{x_2} a\Delta h(x)dx\right] \\ &+ d\sum_{j=1}^{n}\max\left(E_j - s_j, 0\right) + e\sum_{j=1}^{n}\max\left(s_j - T_j, 0\right) \end{aligned} \tag{12}$$

s.t.

$$\begin{aligned} &\sum_{i=0}^{n} g_j y_{ik} \le q, k = i, 2, \cdots m \\ &\sum_{i=0}^{n} x_{ij} = 1,\ j = 0,1,\cdots n \\ &\sum_{j=0}^{n}\sum_{i=0}^{n} x_{ij} = n \\ &\sum_{k=1}^{m} y_{jk} = 1,\ j = 0,1,\cdots n \\ &E_j \le s_j \le T_j,\ j = 0,1,\cdots n \end{aligned} \tag{13}$$

Among them: The formula (13-1) indicates that the cargo capacity per vehicle does not exceed its maximum allowable cargo capacity q.

The formula (13-2) indicates that each customer must be serviced only once, no duplicate service;

The formula (13-3) indicates that all customers are served, not missing any of them.

The formula (13-4) indicates that each customer is serviced by only one car.

The formula (13-5) indicates that the service time of the customer shall be within the acceptable range of the customer.

2.3. Solution methods for vehicle routing model in cold chain logistics

Genetic algorithm is a kind of "generation and detection" iterative search algorithm. It takes all individuals in the population as operand, and every individual is the solution to correspondence problem. There are three main operations: selection, crossover and mutation. Apply Matlab7.0, compile the computer program which is suitable for the algorithm model, complete the solving process on the distribution problem, and obtain the optimal path, to achieve the guidance of the actual problem.

Structure the receiving points for fresh perishable goods as the chromosomes in the solution vector of distribution route optimization problem by using the natural number coding method. Make the solution vector in mathematical model into a chromosome which length is m+1 to express a feasible solution (feasible distribution route), that is, the first vehicle sets out from "0",after the completion of the tasks "i11,i12,i13, …i1t", it backs to" 0 ", which form a sub path 1; The second vehicle resets out from " 0 " to complete the tasks"i21,i22,i23, …,i2t"which are not visited before, then it also backs to "0" to form the sub path 2; Repeat in this way until all the tasks are completed.

For example, the distribution routes of chromosome 014502306780 are as follows:

Sub path 1: distribution center 0→customer 1 → customer 4→ customer 5 → distribution center 0.

Sub path 2: distribution center 0 → customer 2 →customer 3 → distribution center 0.

Sub path 3: distribution center 0→customer 6→ customer 7→ customer 8 → distribution center 0.

These sub paths' chromosome structures are ordered, if task 1and 4 exchange position in sub path 1, then the objective function value is changed; but the chromosome structures between sub paths are disordered, if the sub paths 1 and 2 exchange position will not affect the objective function value.

3. Results and discussions

3.1. Overview of living example

In order to verify and improve the effectiveness of genetic algorithm, we take the distribution process of Fuzhou national express refrigerated transport co., LTD for the customers in the urban area as an example. The number of distribution center is "0", which conducts distribution services for 30 customer points in the urban area. According to the information provided by the third-party cold chain logistics distribution business, the goods delivered to the supermarket are some fresh vegetables which are selling every day like cabbages, Chinese cabbages, tomatoes and potatoes, they can't be tainted by other odor, and their time limit of preservation is 12 hours. When the outside temperature exceeds 20 degrees, the temperature of the refrigerator car should be controlled within 2-15 degrees; when the outside temperature is lower than 20, the refrigerator car should deliver goods in normal temperature.

The coordinate value of each distribution point (employ the Beijing coordinate system), time window constraints and service time, and the quantity demanded in each distribution point, the delivery distances which are calculated by the cold chain logistics distribution optimization system see the attached sheet. The carrying capacities of transport vehicles which are equipped by company are respectively ISUZU III refrigerator cars with 3 t, 5 t, 8 t, refrigerator cars with 11 t mainly see Table 1. All sections are not forbidden segments, and the average running speed of the vehicles in the process of distribution is 35 km/h, the unit price has consulted market real price, as shown in table 5. Arrange the distribution routes reasonably to fully meet the time window constraints of the distribution points.

Table 1. The demand of different PeiSongDian distribution distance

Number	X coordinates	Y coordinates	Demand	The first to accept service time	Accept the latest service time	Service time
0	13271.603	2 896.715	0	6：15	17:00	0
1	13270.702	2 998.124	2	7：00	9:45	30
2	13270.466	2 900.727	2.5	7：00	10:00	45
3	13269.094	2 899.413	1	6：45	14:00	15
4	13254.365	2 900.727	3	6：45	12:00	30
5	13265.366	2 899.418	2	8：00	15:00	15
7	13271.607	2 896.715	2	7：00	17:30	15
7	13270.702	2 898.861	2	6：45	18:00	15
8	13270.466	2 900.727	1	6：15	14:00	30
9	13269.093	2 899.313	1.5	6：30	14:30	30
10	13254.365	2 900.727	3	7：00	13:30	20
11	13265.367	2 999.418	2	6：45	14:00	30
12	13271.603	2 896.715	2	6：15	15:40	30
13	13270.702	2 898.251	1	7：00	14:00	30
14	13270.446	2 900.727	1	7：30	17:30	30
15	13269.093	2 869.413	3	6：45	18:00	15
16	13254.365	2 900.723	2	6：15	11:00	15
17	13265.358	2 899.418	4	7：00	12:00	15
18	13271.603	2 839.415	2.5	8：30	18:00	20
19	13270.702	2 900.727	2.5	6：45	14:30	30
20	13870.466	2 899.418	2	6：15	14:00	30
21	13269.093	2 897.715	2	8：00	14:00	30
22	13554.365	2 428.861	2	7：00	17:00	45
23	13245.366	2 899.413	3	6：45	14:00	15
24	13271.603	2 911.727	3	6：15	14:30	15
25	13225.702	2 899.418	1	7：00	18:00	45
26	13270.466	2 896.715	1	7：00	13:00	30
27	13219.093	2 898.861	4	6：45	14:00	30
28	13254.365	2 899.418	2	7：00	14:00	25
29	13275.366	2 896.715	2.5	6：45	12:00	35
30	13265.366	2 878.861	1	6：00	14:00	15

Table 2. Cluster analysis results

The vehicle number	The customer points	The customer number	Bearing capacity of the vehicle
1	21,24,27,22,28	5	8
2	25,29	2	9.5
3	9,23,26,30	5	8.5
4	14,15,18,20	1	9
5	7,10,11,13	4	8
6	3,4,6,12,19	3	9
7	1,2,5,8,16,17	2	10

Table 3. The delivery of improved genetic algorithm for time window to check

Vehicle	The customer number	Client access order	Distribution range (km)	Distribution range (km)	Delay time (m)	Algorithm to calculate time (s)
1	5	0-27-22-28-24-21-0	15.477	0	0	2.275
2	2	0-25-24-0	27.095	0	0	1.769
3	3	0-23-25-30-9-0	17.822	0	0	2.288
4	2	0-21-14-15-18-0	13.498	0	0	2.703

5	2	0-5-11-14-10-0	16.526	0	0	3.688
6	3	0-4-3-6-12-19-0	14.658	0	0	3.131
7	4	0-1-3-8-14-17-5-0	12.522	0	0	3.219

Table 4. Delivery time window to check the standard genetic algorithm

Vehicle	The customer number	Client access order	Distribution range (km)	Distribution range (km)	Delay time (m)	Algorithm to calculate time (s)
1	5	0-27-22-28-24-21-0	13.477	0	0	2.247
2	2	0-25-24-0	24.025	0	0	1.769
3	3	0-23-25-30-9-0	12.827	0	0	2.388
4	2	0-21-14-15-18-0	13.494	0	0	2.503
5	2	0-5-11-14-10-0	15.226	0	0	3.621
6	3	0-4-3-6-12-19-0	14.658	0	0	3.231
7	4	0-1-3-8-14-17-5-0	12.523	0	0	3.219

3.2. Example analysis

Under the good road condition, adopt large trucks as far as possible to carry out a joint distribution for improving the full load rate and reducing operating costs. According to the specific requirements of the distribution of vegetable products, select the truck with 11 t as a distribution vehicle to solve the problem.

According to the data in Table 1, divide customer points according to the regions of customer points and the limit load capacity of 11t vehicles based on good road condition. The results of cluster analysis see Table 2 (each serial number represent the vehicle number of each transportation route).

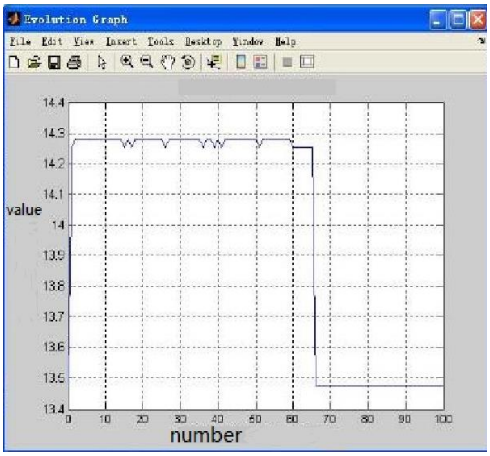

Figure 2. The improved genetic algorithm for the calculation process

Set the specified population number n = 100, the maximum evolution algebra C=100, crossover probability Pc=0.9, mutation probability Pm=0.02 by using the proposed improved genetic algorithm. To achieve rapid search and get the optimal distribution routes with the help of Matlab 7.0.

Figure 2 is the improved genetic algorithm for the calculation process of the first routes; Figure 3 is the standard calculation process of genetic algorithm.

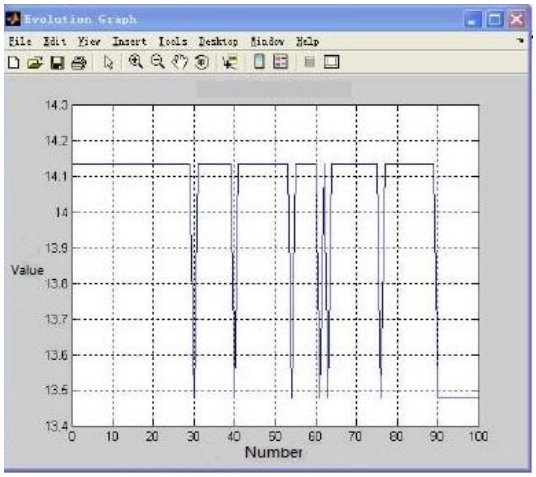

Figure 3. The standard calculation process of genetic algorithm

The distribution time of the above 30 distribution points are within the time window, so there is no penalty cost. The distribution routes in Table 5 appear the violation of the restrictions of time window. Therefore, there should be a corresponding penalty cost, we can see that the improved genetic algorithm has significantly improved in computing speed and efficiency when compared with the standard genetic algorithm.

Check each distribution task in list 3, the distribution time of the above 30 distribution points are within the time window, so there is no penalty cost. The distribution routes on Table 4 appear the violation of the restrictions of time window. Therefore, there should be a corresponding penalty cost. Contact Table 2, we can see that the improved genetic algorithm has significantly improved in computing speed and efficiency when compared with the standard genetic algorithm.

3.3. Results Analysis

According to the results of the comprehensive calculation, we can know that the total cost of the distribution by the improved genetic algorithm is 6 192.2 RMB, and the total cost by standard genetic algorithm is 7105.8 RMB, in which the transport cost is the largest cost of the project, which accounts for about 58.5%-68.4%.

The total sum of energy cost and damage cost accounts for about 20.06%-23.02% of the total cost of distribution. If delivery goods in the normal temperature, the variable cost of transportation accounts for about 22.04%-24.57% of the total cost of the distribution, and the fixed cost accounts for 49.98%-57.62%. Therefore, in the distribution of fresh products, only considering the energy costs and the damage costs can reflect the meaning of cold chain logistics distribution. At the same time, the damage costs in cold chain logistics is significantly lower than that in the normal temperature logistics; it helps to reduce the cost of fresh food distribution, and proves the practical value of the research.

Compare the total distribution cost of the improved genetic algorithm with that of the standard genetic algorithm, the optimal distribution routes which are obtained by using improved genetic algorithm can not only satisfy the time window constraints between chain stores and vehicle capacity constraints, but also in computing speed and efficiency. Standard genetic algorithm only considers the capacity constraints of distribution vehicles, and does not take the time window constraints of the chain stores into account, which increases the penalty cost. Therefore, the improved genetic algorithm adopted in this research is better than the standard genetic algorithm in solving the optimization problem of cold chain goods distribution routes.

4.Conclusions

Take the distribution of the national express refrigerated transport company as an example to verify the basic model of cold chain logistics distribution routes. If the transportation cost and the number of customers are consistent in per unit mileage, the longer service mileage from distribution center to the customers, the greater total transportation cost. Therefore, the total cost of vehicle transport is proportional to service mileage. The greater spoilage costs per product caused by the accumulation of mileage and the lapse of time, the higher total damage costs. The higher unit price, the greater total damage costs of fresh products caused by transport time and car door opening. Hence, the damage cost is proportional to the transport time and the unit price of goods

Divide customer points according to the regions of customer points and the limit load capacity of 11t vehicles based on good road condition, cluster analysis of results, respectively use the standard genetic algorithm and the improved genetic algorithm to calculate under the same control parameters, compare them and obtain the results. The results show that the improved genetic algorithm is superior to the standard genetic algorithm in the calculation of the speed and efficiency.

5.References

Hoang, H.M., Alvarez, G. (2012). Combined deterministic and stochastic approaches for modeling the evolution of food products along the cold chain. *Part I: Methodology. International Journal of Refrigeration*, 35(4), 907-914.

Lan, H. (2012). Decision-making on food cold chain collaborative distribution models.

Advances in Information Sciences and Service Sciences, 4(23), 660-666.

Li, C.M., Nien, C.C. (2010). Development of wireless sensor module and network for temperature monitoring in cold chain logistics. *Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)*, 43(6), 1707-1711.

Lan, H., Xue, H. (2013). Classification and application on food cold chain collaborative distribution models. *LISS 2012 - Proceedings of 2nd International Conference on Logistics Informatics and Service Science*, 2(12), 123-128.

Montanari, R. (2008). Cold chain tracking: a managerial perspective. *Trends in Food Science and Technology*, 19(8), 425-431.

Palacio, F., Nuin, M.Z. (2009). RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain. *Journal of Food Engineering*, 93(4), 394-399.

Xu, Y., Gong, B. (2016). A feasibility research on the mechanism of cold chain business in Deppon logistics, *International Journal of Technology*, 9(3),157-168.

Wu, L.Z., Zhao, Y. (2013). Cold chain logistics temperature monitoring system based on internet of things technology. *Applied Mechanics and Materials*, 4(16), 1969-1973.

Wang, X. (2012). Experimental study of response characteristics of gas sensors for monitoring table grape cold-chain logistics. *Nongye Jixie Xuebao/Transactions of the Chinese Society for Agricultural Machinery*, 47(1), 240-246.