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Multi-Objective Cold Chain Path Optimization Based on Customer Satisfaction

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Abstract

To improve customer satisfaction of cold chain logistics of fresh agricultural goods enterprises and reduce the comprehensive distribution cost composed of fixed cost, transportation cost, cargo damage cost, refrigeration cost, and time penalty cost, a multi-objective path optimization model of fresh agricultural products distribution considering client satisfaction is constructed. The model is solved using an enhanced Elitist Non-dominated Sorting Genetic Algorithm (NSGA-II), and differential evolution is incorporated to the evolution operator. The algorithm produced by the revised algorithm produces a better Pareto optimum solution set, efficiently balances the relationship between customer pleasure and cost, and serves as a reference for the long-term growth of organizations.

Keywords

Cold Chain Logistics, Customer Satisfaction, Elitist Non-Dominated Sorting Genetic Algorithm, Multi-Objective Optimization

1. Introduction

China's market demand for meat, fruits and vegetables, and other fresh agricultural products has increased substantially in recent years. The annual demand for vegetables, fruits, meat, and aquatic products in China has exceeded 90 million tons, 76 million tons, 54 million tons, and 42 million tons, respectively, according to the "China Cold Chain Logistics Research Report", fostering the exponential expansion of China's cold chain transportation and storage. Nonetheless, numerous serious problems exist at the present. The rapid growth in people's demand for high-quality consumer goods, as well as market players' demand for high-quality logistics services, has created new development requirements for our cold chain logistics of fresh agricultural products, and cold chain logistics is confronted with new development possibilities as well as difficulties prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

There are many studies on the path optimization of cold chain distribution of fresh agricultural products by scholars at home and abroad. To overcome the problem, Zheng *et al.* [1] developed a cold chain route optimization model that takes into account intermodal transportation and customer happiness, and he referred to an enhanced particle swarm optimization technique; Xiong [2] modified the ant colony optimization method by include transit time, transportation cooling, and road variables; Peng [3] investigates the expenses as well as efficacy of cold chain transportation, develops a fresh food cold chain transportation model, and determines the ideal path using an enhanced genetic algorithm; Tao *et al.* [4] developed a cold chain logistics distributing truck routing model with the lowest total cost while accounting for carbon emissions, included chaotic mapping into pheromone updating, and paired it with the simulated annealing approach to reach the local optimal solution.

2. Problem Description and Hypothesis

This article primarily investigates a distribution center's distribution channel to various consumers. The following assumptions are used to aid in the development of the mathematical model:

1) The distribution center has a sufficient number of vehicles of the same model, and the maximum load capacity of cars, customer demand and time frame, and client location are all known.

2) Each truck departs from and returns to the same distribution location after performing the distribution assignment.

3) All client demands may be addressed, and each customer only needs to be seen once.

4) The quality of all fresh agricultural goods peaks as they leave the distribution hub and subsequently begins to deteriorate.

5) During the delivery procedure, the vehicle speed is determined using the average speed and remains constant.

3. Model Formulation

3.1. Description of Parameters and Variables

K: Total number of vehicles in distribution center, $K = \{1, 2, 3, \dots, k\}$;

N: Total number of customer points, $N = \{1, 2, 3, \dots, i, \dots, j \dots, n\}$;

t_i: The time when vehicle k arrives at customer point i;

t_0: The departure time of vehicle k from the distribution center;

t_{si}: Unloading time of vehicle k at customer point i;

t_{ijk}: Travel time of vehicle k from customer point i to customer point j;

θ_1: Coefficient of rottenness during transportation;

θ_2: Coefficient of rottenness during unloading;

α_1: Time satisfaction weight;

α_2: Freshness satisfaction weight;

f_k: The fixed cost of vehicle k;

f_d: Transportation cost per unit distance;

d_{ij}: The distance from customer point i to customer point j;

P_1: Unit cooling cost;

H_1: Heat load during transportation;

H_2: Heat load during unloading;

q_i: The quantity demanded at customer point i;

Q_i: Product weight on vehicle k when it leaves customer point i;

β_1: Penalty cost per unit time of early arrival;

β_2: Penalty cost per unit time of delayed arrival;

$[eT_i, lT_i]$: Delivery time window acceptable to the customer;

$[ET_i, LT_i]$: Customer's desired delivery time window;

x_{ijk}: Variable of decision, if vehicle k is distributed from customer point i to customer point j, then $x_{ijk} = 1$ and 0 otherwise;

x_{ik}: Variable of decision, if vehicle k serves customer point i, then $x_{ik} = 1$ and 0 otherwise.

3.2. Analysis

The distribution center and the customer will agree on a delivery time, but due to driving conditions, weather, and other factors, the delivery may not be made on time, affecting customer satisfaction and product quality and resulting in the corresponding penalty cost. The connection between customer satisfaction and time S_{i1} is as follows:

$$S_{i1} = \begin{cases} 1, & eT_i \le t_i \le lT_i \\ \dfrac{t_i - ET_i}{eT_i - ET_i}, & ET_i < t_i < eT_i \\ \dfrac{t_i - lT_i}{LT_i - lT_i}, & lT_i < t_i < LT_i \\ 0, & \text{others.} \end{cases} \tag{1}$$

The fresh agricultural goods in the vehicle come in touch with the outside air owing to the opening of the refrigerated car door during unloading, and the internal temperature rises so the freshness rottenness coefficient $\theta_2 > \theta_1$ [5]. The customer satisfaction function S_{i2} of the freshness of fresh agricultural goods at the consumer point may be described in this situation as [6]:

$$S_{i2} = 1 - \left(1 - e^{-\theta_1(t_i - t_0)}\right) - \sum_{k=0}^{K}\sum_{i=1}^{N}\left(1 - e^{-\theta_2 t_{si}}\right) \tag{2}$$

$$S_i = \alpha_1 S_{i1} + \alpha_2 S_{i2} \tag{3}$$

The fixed cost C_1 may be written as:

$$C_1 = \sum_{k=1}^{K} f_k \tag{4}$$

The transportation cost C_2 may be stated as:

$$C_2 = \sum_{k=1}^{K}\sum_{i=0}^{N}\sum_{j=0}^{N} d_{ij} x_{ijk} f_d \tag{5}$$

The cost of refrigeration incurred during transit $C_3^{'}$ is given as:

$$C_3^{'} = \sum_{k=1}^{K}\sum_{i=0}^{N}\sum_{j=0}^{N} P_1 H_1 t_{ijk} x_{ijk} \tag{6}$$

The calculation formula of heat load during transportation H_1 is as follows:

$$H_1 = (1+\lambda)\cdot R \cdot \sqrt{S_W \cdot S_N} \cdot \Delta T \tag{7}$$

In the formula, λ is the heat leakage coefficient of the deterioration of the carriage, R is the heat transfer rate, S_W is the surface area inside the carriage, S_N is the surface area inside the carriage, and ΔT is the temperature difference between the inside and outside the carriage.

The refrigeration cost of the refrigerated vehicle in the unloading project $C_3^{''}$ may be written as:

$$C_3^{''} = \sum_{k=1}^{K}\sum_{i=0}^{N} P_1 H_2 t_{si} x_{ik} \tag{8}$$

The calculation formula of heat load in unloading process H_2 is as follows:

$$H_2 = \sigma(0.54V_k + 3.22)\Delta T \tag{9}$$

In the formula, σ is the frequency coefficient of opening doors, and V_k is the volume inside the carriage.

To sum up, the expression of refrigeration cost of refrigerated vehicle C_3 is:

$$C_3 = P_1\left[\sum_{k=1}^{K}\sum_{i=0}^{N}\sum_{j=0}^{N}(1+\lambda)\cdot R\cdot\sqrt{S_W\cdot S_N}\cdot\Delta T\cdot t_{ijk}x_{ijk} + \sum_{k=1}^{K}\sum_{i=0}^{N}\sigma(0.54V_k+3.22)\Delta T\cdot t_{si}x_{ik}\right] \tag{10}$$

The cost of products damage due to C_4 shipping and unloading may be stated as:

$$C_4 = \sum_{k=1}^{K}\sum_{i=1}^{N} x_{ik} Pq_i\left[1-e^{-\theta_1(t_i-t_0)}\right] + \sum_{k=1}^{K}\sum_{i=1}^{N} x_{ik} PQ_i\left(1-e^{-\theta_2 t_{si}}\right) \tag{11}$$

The time penalty cost function is as follows:

$$C_5(i) = \begin{cases} Max, t_i < ET_{i,} t_i > LT_i \\ \beta_1(eT_i - t_i), ET_i < t_i < eT_i \\ 0, eT_i < t_i < lT_i \\ \beta_2(t_i - lT_i), lT_i < t_i < LT_i \end{cases} \tag{12}$$

$$C_5 = \sum_{i=1}^{N} C_5(i) \tag{13}$$

3.3. Objective Function and Constraints

This work develops a multi-objective model of fresh agricultural product distribution that takes customer satisfaction into account, with the goal of achieving the lowest overall distribution cost and the best satisfaction of customers.

$$MinC = C_1 + C_2 + C_3 + C_4 + C_5 \tag{14}$$

$$MaxS_i = \alpha_1 S_1 + \alpha_2 S_2 \tag{15}$$

$$\sum_{i=1}^{N} x_{ik} q_i \le Q, \forall k \in K \tag{16}$$

$$\sum_{i=1}^{N} x_{ijk} = \sum_{j=1}^{N} x_{ijk}, \forall k \in K \tag{17}$$

$$\sum_{i=1}^{N} x_{i0k} = \sum_{j=1}^{N} x_{0jk}, \forall k \in K \tag{18}$$

$$\sum_{k=1}^{K} x_{ik} = 1, \forall i \in N \tag{19}$$

$$t_j = t_i + t_{si} + t_{ijk}, \forall i, j \in N \tag{20}$$

$$x_{ijk} \in \{0,1\}, x_{ik} \in \{0,1\} \tag{21}$$

The goal functions represented by Equations (14) and (15) are the minimization of total cost and the maximum of customer contentment. According to Equation (16), the total weight loaded by the vehicle does not exceed the vehicle's rated load. Equations (17) and (18) show that each vehicle departs from the same distribution center and returns to it after completing the distribution duty. According to Equation (19), each consumer can only be served once by a single vehicle. The job of vehicle dispersal is represented by Equation (20). After arriving at customer point i, the van unloads products for customer i before proceeding to customer point j for distribution; Equation (21) reflects the decision variable constraint.

4. Design of Algorithm

4.1. NSGA-II

This article handles the multi-objective route optimization issue with the goal of achieving the overall optimum in logistics distribution while maximizing customer satisfaction and minimizing total cost. Deb *et al.* presented NSGA-II in 2002 to tackle the multi-objective issue by incorporating non-dominated sorting and congestion computation, as well as applying the Pareto optimum solution to choose excellent individuals [7]. The use of the elite retention method guarantees that superior people are maintained in the population and enhances the multi-objective programming model's optimization performance.

4.2. Differential Evolution

The grade vector is generated based on the nondominated hierarchy and random numbers and used to perform binary tournament selection on the population. Here, the Evolution operator is improved by adding Differential Evolution (DE). The differential change algorithm is used for further mutation and crossover operations for each child solution; that is, the variance vectors of two randomized solutions plus a scaling factor is used to update the current solution, and then a crossover probability is used to decide whether to retain the updated coding bits. Finally, the feasibility after DE is tested, and the elements that are infeasible are rectified.

The initial population is produced at random, and each individual is represented by a vector of real integers. For each person, a mutation operation is carried out, in which three distinct individuals are chosen at random from the population, their difference vectors are computed, and they are joined to the present individual to produce a mutation vector. A crossover operation is performed for each individual, that is, elements are randomly selected from the variation vector and the current individual to form a crossover vector. The selection operation is performed for each individual, that is, the fitness value of the cross vector and the current individual is compared, and the better one is selected as the individual of the next generation. Repeat the above cross mutation operation until the termination condition is met.

5. Example Analysis

5.1. Given Condition

In this work, the route of a fresh agricultural product company's cold chain transport trucks in Jinan city is improved, and a distribution center completes the distribution to 20 customers, with consumer demand information presented in **Table 1**.

The distribution center opens at 5:00 a.m., the vehicle's average speed is 40 km/h, the fixed cost of each refrigerated car working every day is 400 yuan, the unit distance cost is 1.2 yuan/km, the unit price of fresh agricultural products is 40 yuan/kg, the vehicle's unit cooling cost is 1.5 yuan/kcal, and the rated load of the vehicle is 1.7 t. The open door frequency coefficient is set at one. **Table 2** shows the values for the remaining parameters.

5.2. Results

In this paper, the MATLAB 2020a software is used to solve the problem, so that the maximum iteration number is 500, the population number is 100, the crossover probability is 0.75, and the mutation probability is 0.2. Through the calculation of the improved NSGA-II algorithm, different non-dominated solutions and the corresponding comprehensive cost and customer satisfaction are obtained.

The numerical convergence of comprehensive cost and customer satisfaction is shown in **Figure 1** and **Figure 2**, the comprehensive cost decreases with the increase of iterations, and customer satisfaction increases with the increase of iterations. Therefore, there is a negative correlation between cost and customer satisfaction, the obtained Pareto optimal solution set is shown in **Figure 3**.

Table 1. Customer demand information.

Table Head	X	Y	Quantity demanded	Expected time	Acceptable time	Service time
0	8.15	33.35		-	-	-
1	12.64	10.37	300	5:30-6:00	5:30-6:00	10
2	21.36	19.63	260	5:00-5:30	5:00-5:30	15
3	22.11	9.84	400	5:30-6:00	5:00-6:00	15
4	31.73	13.11	180	5:00-5:30	5:00-5:30	10
5	36.86	15.28	900	5:00-5:30	5:00-5:30	25
6	6.87	15.24	190	5:30-6:00	5:30-6:00	5
7	38.57	8.24	400	5:00-5:30	5:00-5:30	15
8	16.87	13.75	370	5:30-6:00	5:00-6:00	10
9	26.73	17.23	700	5:30-6:00	5:00-6:00	20
10	9.83	26.74	300	5:00-5:30	5:00-5:30	10
11	26.93	34.64	240	5:30-6:00	5:30-6:30	10
12	48.66	4.02	130	5:00-5:30	5:00-6:00	5
13	43.29	20.74	200	5:30-6:00	5:30-6:00	10
14	28.76	3.89	450	5:00-5:30	5:00-6:00	15
15	4.62	7.08	670	5:30-6:00	5:30-6:00	20
16	13.95	27.78	230	5:00-5:30	5:00-5:30	5
17	17.27	4.90	180	5:00-5:30	5:00-5:30	5
18	35.93	5.95	330	5:00-5:30	5:00-5:30	10
19	42.73	10.87	120	5:30-6:00	5:30-6:30	10
20	41.65	24.84	400	5:00-5:30	5:00-5:30	15

Table 2. Parameters value.

Parameters	Value	Parameters	Value
θ1	0.002	SW	36 m^2
θ2	0.003	SN	33 m^2
α1	0.6	ΔT	20˚C
α2	0.4	Vk	13.2 m^3
λ	0.1	$\beta 1$	50 yuan/h
R	2.49 kcal/(h·m^2·˚C)	$\beta 2$	100 yuan/h

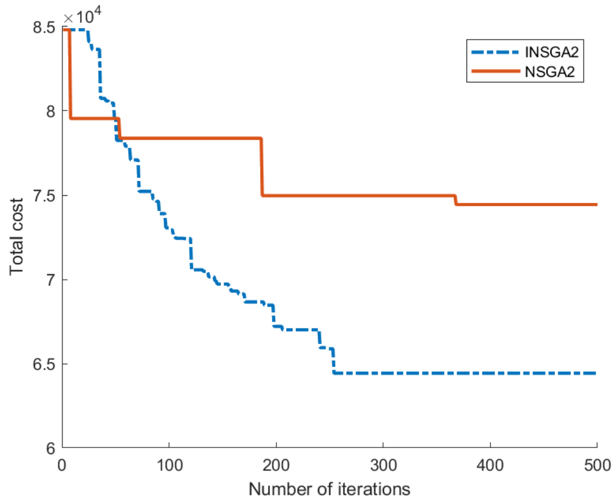

Figure 1. Cost iteration curve.

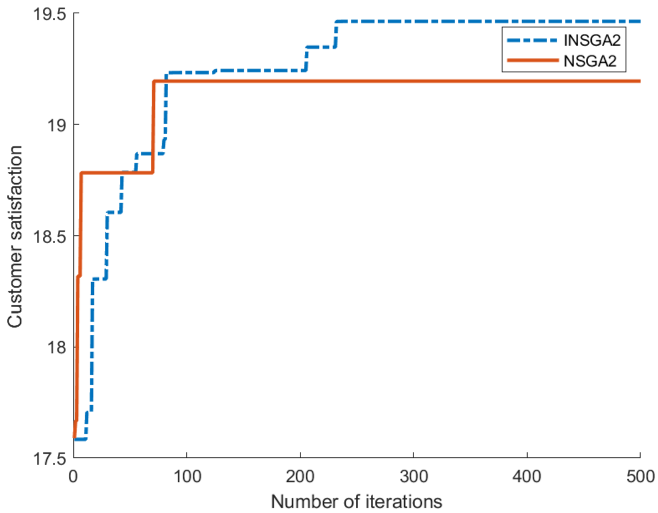

Figure 2. Customer satisfaction iteration curve.

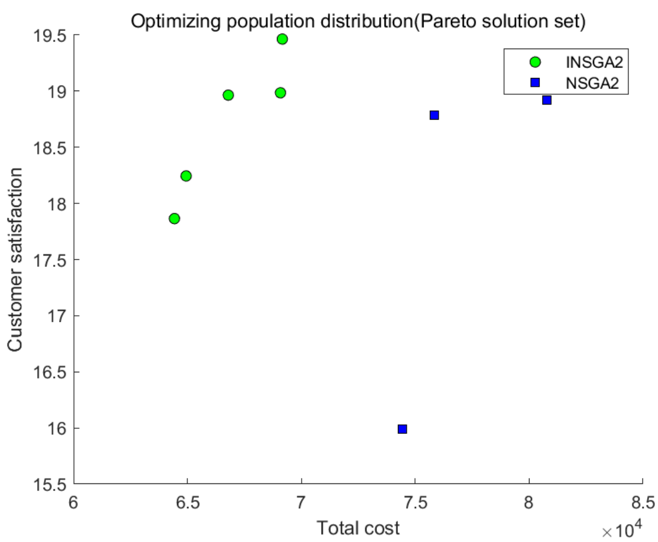

Figure 3. Optimizing population distribution.

Figure 1 and **Figure 2** show that the optimized NSGA-II algorithm achieves a reduced average comprehensive cost and converges after 200 iterations, which is faster than the method prior to modification. At the same time, it may achieve greater average client satisfaction, therefore the upgraded NSGA-II algorithm outperforms the NSGA-II algorithm in terms of optimization performance.

Figure 3 shows that the modified NSGA-II method can produce 5 pareto optimum solution sets, while the NSGA-II algorithm can obtain 3 pareto optimal solution sets. The value of the upgraded NSGA-II's optimal solution set is much higher than that of the standard NSGA-II.

6. Conclusions

This paper investigates the multi-objective path optimization issue associated with fresh agricultural product distribution, considers the freshness of products and delivery time as indicators to evaluate customer satisfaction for weighted calculation, and establishes the multi-objective path optimization model. To solve the model, the NSGA-II method is utilized, and the revised NSGA-II algorithm adds differential evolution to the evolution operator, which proves the model's feasibility. According to the optimization results before and after the algorithm change, the revised NSGA-II increases convergence time, improves global search ability, is more adaptable to complicated situations, and has superior optimization performance. Better optimization outcomes are possible. The example results show that there is an inverse relationship between the total cost of logistics distribution and client satisfaction, implying that in the procedure of cold chain agricultural product distribution, the sole pursuit of the lowest cost is going to contribute to a reduction in customer satisfaction.

This paper's study result primarily provides an academic foundation for the path optimization of cold chain logistics of small and medium-sized businesses, and does not take into account the effect of road conditions on logistics in practice. Cold chain logistics uses more energy than conventional logistics. Carbon emission considerations might be examined as the low-carbon idea develops.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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