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Collaborative Scheduling Optimization of Perishable Food Production and Distribution based on Genetic Algorithm

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Abstract

Fresh food e-commerce companies generally adopt the scheduling scheme of determining the distribution plan and then arranging the production plan, which is prone to problems such as order delay and production confusion. However, the collaborative optimization problem of perishable food production and distribution studied in this paper can provide them with reasonable distribution routes, Joint scheduling scheme for order production sequence and production staffing configuration. In this paper, on the basis of meeting the customer's time window requirements, aiming at minimizing the fixed cost of vehicles and transportation costs, a joint scheduling model for the production and distribution of perishable food is constructed, and a genetic algorithm is designed to solve the model. Finally, the model is verified by an example. And the effectiveness of the algorithm can effectively provide a reasonable joint scheduling scheme for production and distribution.

Keywords

Perishable Food; Production and Distribution; Collaborative Optimization; Genetic Algorithm.

1. Introduction

In recent years, with the increasing maturity of Internet technology and the transformation of user consumption habits and concepts, the fresh food e-commerce industry has developed rapidly. At the same time, consumers' demand for home delivery has grown rapidly. However, most fresh food e-commerce companies rely on experience to determine the staff scheduling of various positions, which brings chaos in the production process, delays in delivery, and shortages and conflicts of various resources. problem. Due to the short life cycle and perishable characteristics of fresh products, fresh food e-commerce companies organize and arrange distribution immediately after the production and processing is completed. Therefore, how to coordinately optimize production and distribution to reduce the total cost has always been a concern of fresh food e-commerce companies.

For the application research of Integrated Scheduling of Production and Distribution Problem (ISPDP) of perishable products, Amorim P et al. [1] studied and compared the ISPDP problem of perishable products in batch and batch production modes. The calculation example verifies that mass production can reduce the total cost; Belo-Filho M A F et al. [2] designed an adaptive large neighborhood search algorithm to solve the ISPDP of perishable products; Seyedhosseini S M et al. [3] proposed a collaborative optimization model for the production planning and distribution planning of perishable products considering batch and inventory paths, and developed a heuristic algorithm to solve the calculation example; Moons S et al. [4] collated and consolidated existing production and delivery integration scheduling issues and categorized them based on the focus of the study; Devapriya P et

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al. [5] studied the ISPDP problem of fresh products under the constraint of short shelf life of fresh products, and verified the optimization model of fresh product production and distribution based on genetic algorithm; Lacomme P et al. [6] studied the integration of production and transportation of fresh products with single production facility and multiple vehicles Devapriya P et al. [7] established an optimization model of ISPDP for fresh products based on the configuration of production personnel, and designed a new branch pricing algorithm to solve the model according to the characteristics of the model; Liu Ling and Liu Sen [8] established an integrated production-distribution optimization model for fresh products with the objective function of minimizing delivery time, and designed an improved large neighborhood search algorithm to solve the problem; Li Yantong et al. [9] studied the ISPDP of fresh products under the influence of food packaging factors, which described the new problem based on mixed-integer linear programming, and propose two branch-and-cut algorithms whose calculation results show that the integrated optimization of packaging and production routes can bring economic benefits; Solina V et al. [10] established a comprehensive scheduling optimization model for production and distribution with the goal of minimizing production and distribution costs under the constraints of production and processing conversion time and product perishability. Based on the previous literature research results, this paper proposes a joint scheduling problem of perishable food production and distribution with the goal of minimizing the total cost of vehicle fixed cost and transportation cost, and uses matlab to simulate and verify.

2. Problem Description

A fresh food e-commerce production and distribution center provides door-to-door delivery to multiple customers. After the customer order is received by fresh food e-commerce platform. Each order has different types of products and cannot be split. Immediately after the production of the order is completed, the vehicles will be organized in batches for distribution, ignoring the loading time.

Considering that the complexity of the problem and the ease of model construction and solution, it is assumed that:

(1) Information such as the customer's geographic location, the time window for required services, the demand for products and the shelf life are known;

(2) The machining center adopts the parallel machining mode, and is processed by multiple processing personnel with the same ability. In order to complete the processing as soon as possible, the waiting time of order processing is not considered;

(3) Each order is produced by one production staff, the order cannot be split and is produced only once, ignoring the switching time and cost between different orders;

(4) Each customer point is served by only one vehicle, the customer point has a time window, and the delivery vehicle must arrive within the time window of each delivery point. If they arrive early, they need to wait. If they are late, they will be rejected;

(5) A production distribution center has multiple distribution vehicles responsible for distribution, and each vehicle is responsible for a route, and the departure time of the vehicle from the distribution center is not earlier than the processing completion time of the last order on the corresponding route. The vehicle returns to the distribution center immediately after completing a distribution task.

3. Model Construction

3.1 Parameter Description

I : The set of customer orders, I={1,2,…,i};

N : The collection of customer orders and production distribution centers, node 0 represents the distribution center, and N={0} ∪ I;

M : The set of production personnel, M={1,2,…,m};

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K : The set of available vehicles, K={1,2,…,k};
Q : The capacity of each vehicle;
di : The demand for customer order i;
α : The unit distance transportation cost of the vehicle;
β : The fixed cost of the vehicle;
[Ei , Li] : The time window during which service is requested by customer order i;
si : The time required for the service of customer order i;
tij : The transit time from i to j;
wi : The required time to wait for customer order i;
pi : The time required to produce customer order i;
tisp: The start time of processing customer order i;
tiarr: The moment when the vehicle arrives at customer order i;
tkstartand tkend: The moment when vehicle k starts to deliver and the moment when it returns to the delivery center, respectively;
xijk : 1 if vehicle k visits arc (i,j), otherwise 0;
yik : 1 if vehicle k is responsible for delivering customer order i, otherwise 0;
zijm : 1 if production person m is responsible for producing order i and then directly processing order j, otherwise it is 0.

3.2 Modeling

In the proposed joint scheduling problem of perishable food production and distribution, the total cost of order production is fixed, so this paper takes the minimization of the total distribution cost including the fixed cost of the vehicle and the transportation cost as the optimization goal, and the model is established as follows:

Objective :

$$\min f = \alpha \sum_{k\in K}\sum_{i\in N}\sum_{j\in N} t_{ij} x_{ijk} + \beta \sum_{k\in K}\sum_{i\in I} x_{0ik} \tag{1}$$

Subject to:

$$\sum_{j\in I} z_{0jm} = 1 \tag{2}$$

$$\sum_{m=1}^{M}\sum_{i=0}^{I} z_{ijm} = \sum_{m=1}^{M}\sum_{j=0}^{I} z_{ijm} = 1, i \neq j \tag{3}$$

$$\sum_{\substack{i=0,\\ i\neq l}}^{I} z_{ilm} = \sum_{\substack{j=0,\\ j\neq l}}^{I} z_{ljm} \tag{4}$$

$$t_j^{\mathrm{sp}} = \left(t_i^{\mathrm{sp}} + p_i\right) z_{ijm}, \quad i \neq j \tag{5}$$

$$\sum_{k\in K} y_{ik} = 1 \tag{6}$$

$$\sum_{j\in N} x_{ijk} = y_{ik} \tag{7}$$

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$$\sum_{i\in N} x_{ijk} = \sum_{i\in N} x_{jik} \tag{8}$$

$$\sum_{k\in K}\sum_{i\in I} x_{0ik} = \sum_{k\in K}\sum_{j\in I} x_{j0k} = 1 \tag{9}$$

$$\sum_{i\in I} d_i y_{ik} \le Q \tag{10}$$

$$t_k^{\text{start}} \ge \max_{i\in I} y_{ik}\left(t_i^{\text{sp}} + p_i\right) \tag{11}$$

$$t_j^{\text{arr}} = t_i^{\text{arr}} + s_i + t_{ij} + w_i \le L_j \tag{12}$$

In the above model:

Equation (1) indicates that the total distribution cost is the smallest, where the total distribution cost includes fixed cost and transportation cost;

Equation (2) shows that at most only one order is processed first by the processing personnel m;

Equation (3) indicates that all orders are produced and processed;

Equation (4) indicates the order processing sequence of processing personnel m;

Equation (5) represents the completion time of order j that is produced and processed next to order i;

Equations (6) and (7) indicate that all customer orders are serviced and accessed only once;

Equation (8) represents the path flow balance;

Equation (9) ensures that each vehicle must return to the distribution center after delivery;

Equation (10) ensures that each path satisfies the vehicle capacity constraint;

Equation (11) indicates that the start delivery time of each route is not earlier than the production completion time of all orders on the route;

Equation (12) restricts that the customer time window requirements are met.

4. The Genetic Algorithm Construction

The problem proposed in this paper has been proved to be NP-hard. However, CPLEX is only suitable for solving small-scale and relatively simple examples in real life, so it is impossible to obtain the solution of the problem within a reasonable time range through CPLEX. The intelligent optimization algorithm has been widely used in large-scale and high-complexity cases. According to the characteristics of the proposed problem and model, this paper uses the Genetic Algorithm(GA) to solve the constructed model. The basic principle is: first randomly generate an initial population with a certain number of individuals, that is, the initial solution; then calculate the fitness value of each individual according to the fitness function, select a high-quality solution with a larger fitness value to perform crossover and mutation operations and generate new subgroups. Next, the new offspring are merged as the initial population of the next round of loop iteration. The above selection, crossover and mutation operations are repeatedly iterated until the iteration stop condition is met, thereby obtaining the optimal solution of the problem.

4.1 Coding

According to the characteristics of the constructed model, this paper designs the following coding scheme: the chromosome coding adopts natural number coding, and the chromosome contains 3 substrings: the order processing sequence substring X, the processing staff substring Y and the delivery sequence substring Z for processing each order, namely pop=[X,Y,Z]. The advantage of this encoding method is that it is very convenient to directly enter the information into the chromosome without complex calculation and decoding processes. For example, there are 8 customer orders to be served in the processing and distribution center, and there are 3 processing personnel. If the generated chromosome is:

$$(\underbrace{1-8-3-2-4-5-6-7}_{\text{X}}|\underbrace{2-2-2-1-1-1-3-3}_{\text{Y}}|\underbrace{0-1-6-4-3-0-8-5-0-2-7-0}_{\text{Z}})$$

Then the chromosome indicates that processing staff 1 needs to process orders 2-4-5 in sequence, processing staff 2 needs to process orders 1-8-3 and processing staff 3 needs to process orders 6-7 in sequence, and the distribution center needs to send a total of 3 trips: 0-1-6-4-3-0, 0-8-5-0 ,0-2-7-0 and , in which 0 in the substring 3 of the delivery sequence is used to separate different vehicle trips, indicating that the vehicle starts from the distribution center and finally returns to the distribution center.

4.2 Algorithm Initialization

Set the population size to popsize, assuming that 1 chromosome with order size n is randomly generated, and check whether the distribution path substring 3 in the randomly generated chromosome: $\left(0,\ i_{1,1},...,i_{1,n},0\right)$ satisfies the vehicle capacity and customer service time window constraints. If $\sum_{j=1}^{z} d_{i_{1-j}} \le Q$ and $\sum_{j=1}^{z+1} d_{i_{1-j}} > Q$, insert 0 between a pair of clients and if there is no such client pair , insert 0 after moving the client forward or backward by one position. Similarly, do the same when considering customer service time window constraints. Repeat the above steps until the number of chromosomes generated reaches the population size of popsize.

4.3 Cross Operation

The crossover operator in this paper adopts the Position-based Crossover (PBX) crossover method and the single-point crossover method. According to the set crossover probability, the PBX crossover method is used for the substring 1 and the substring 3 of the chromosome, and the single-point crossover operation is used for the substring 2. The operation steps of Position-based Crossover (PBX) are as follows:

Step 1: Randomly select several genes in a pair of chromosomes (parents), the positions may not be consecutive, but the selected positions of the two chromosomes are the same;

Step 2: Generate a progeny, and ensure that the position of the selected gene in the progeny is the same as that of the parent;

Step 3: First find out the position of the gene selected in step 1 in another parent, and then put the remaining genes into the offspring generated in step 2 in order.

4.4 Mutation Operation

The mutation operations in this paper mainly include order reversal mutation and random mutation. According to the set mutation probability, the method of reverse order mutation is adopted for the substring 1 and substring 3 of the chromosome. If the substring 1 and substring 3 of the new offspring obtained after crossover satisfy the conditions of order reverse mutation, then the substring 1 and substring 3 of the new offspring obtained after crossover meet the conditions of order reversal mutation, respectively. Two mutation points are randomly selected for 1 and substring 3, and the gene segments between the mutation points are arranged in reverse order; the method of random mutation is adopted for substring 2, that is, any gene locus is selected for mutation in substring 2, and the value range does not exceed the total number of production staff. For example, the chromosomes is

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$\chi = 12345678 \| 22211133 \| 016430850270$, new chromosomes obtained after mutation is $\chi' = 12354867 \| 11322213 \| 075410680230$.

4.5 Terminate the Algorithm

When the evolutionary algebra of the algorithm reaches the maximum number of iterations of 1000, the algorithm terminates and outputs the result.

5. Example Analysis

5.1 Example Settings

At present, there is no standard test example of ISPDP. The problem processing part studied in this paper is the parallel machine scheduling problem, and the distribution part is the vehicle routing problem with time window(VRPTW). Therefore, the R101 data in the Solomon example of VRPTW research is used for reference. Because Solomon's published research data are dimensionless, all data in this section are dimensionless. Assume that the order production time pi obeys a uniform distribution, pi~[2,5]. And, other experimental parameters are: α is 2, β is 150, Q is 200.

The genetic parameters are set as follows: population size is 100, number of iterations is 1000, crossover probability is 0.8, and mutation probability is 0.2. It is implemented in Matlab 2016b programming language and runs on a computer with 4-core CPU, 2.10 GHz main frequency, 16 GB memory and Windows 10 operating system.

5.2 Experimental Results and Analysis

Table 1. Customers point information

CP	(X,Y)	TW	D	CP	(X,Y)	TW	D
0	(35,35)	(0,230)	0	16	(49,73)	(127,137)	9
1	(49,58)	(88,98)	30	17	(67,5)	(83,93)	20
2	(27,43)	(52,62)	13	18	(56,39)	(142,152)	25
3	(37,31)	(95,105)	10	19	(37,47)	(50,60)	25
4	(57,29)	(140,150)	9	20	(37,56)	(182,192)	36
5	(63,23)	(136,146)	14	21	(57,68)	(77,87)	6
6	(53,12)	(130,140)	18	22	(47,16)	(35,45)	5
7	(32,12)	(101,111)	2	23	(44,17)	(78,88)	15
8	(36,26)	(200,210)	6	24	(46,13)	(149,159)	25
9	(21,24)	(18,28)	7	25	(49,11)	(69,79)	9
10	(17,34)	(162,172)	18	26	(49,42)	(73,83)	8
11	(12,24)	(76,86)	28	27	(53,43)	(179,189)	18
12	(24,58)	(58,68)	3	28	(61,52)	(96,106)	13
13	(27,69)	(34,44)	13	29	(57,48)	(92,102)	14
14	(15,77)	(73,83)	19	30	(56,37)	(182,192)	3
15	(62,77)	(51,61)	10				

Take the order size as 30 and the number of production personnel as 4 as an example for calculation, the algorithm runs 50 times randomly, and the customers point information, see Table 1. The evolution process of the example is shown in Figure 1 . The evolution curve of the total distribution

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cost shows a steady downward trend with the increase of the number of iterations, indicating that the genetic algorithm has good search ability and convergence in the process of solving this problem.

Finally, the optimal scheduling scheme of fresh food cold chain distribution based on freshness and total cost is obtained, as shown in Table 1, in which the third column "The time of production and distribution" lists the production end time of each production staff and the time when the delivery vehicle visits the corresponding customer point. It can be seen from Table 2 that the optimal total cost of the obtained joint dispatch scheme is 1762, and a total of 5 vehicles are required for the delivery task, and the optimal delivery path diagram is drawn according to the joint scheduling scheme, as shown in Figure 2.

Instruction: CP is consumer node; TW is time window; D is demand.

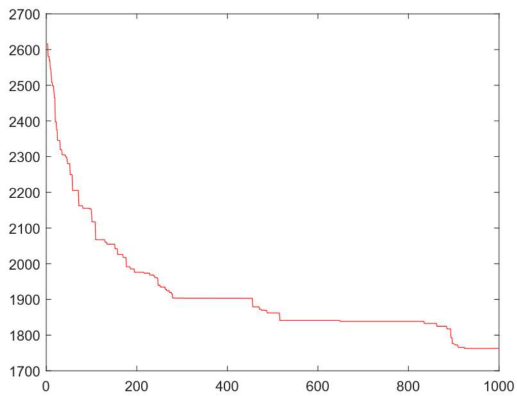

Figure 1. Evolution curve of target total cost

Table 2. The joint scheduling scheme according to the optimal result

Production and distribution joint scheduling scheme		The time of production and distribution	Objective function value
Production staff 1	6-25-23-27-24-29-13-26-30-21-2-16	53	$\tilde{f}=$ 1762
Production staff 2	1-19-12	10	
Production staff 3	10-11-9-17-5-7-8-3	28	
Production staff 4	22-14-20-4-18-15-28	27	
Path number 1	0-23-22-24-6-30-18-0	43-63-76-89-107-134-152-164-195	
Path number 2	0-19-1-3-8-0	28-40-66-106-121-140	
Path number 3	0-10-11-9-7-25-17-5-0	23-41-62-81-107-135-163-192-232	
Path number 4	0-20-13-14-12-2-0	48-69-95-120-151-176-198	
Path number 5	0-16-15-21-28-29-27-26-0	53-93-117-137-164-180-196-210-236	

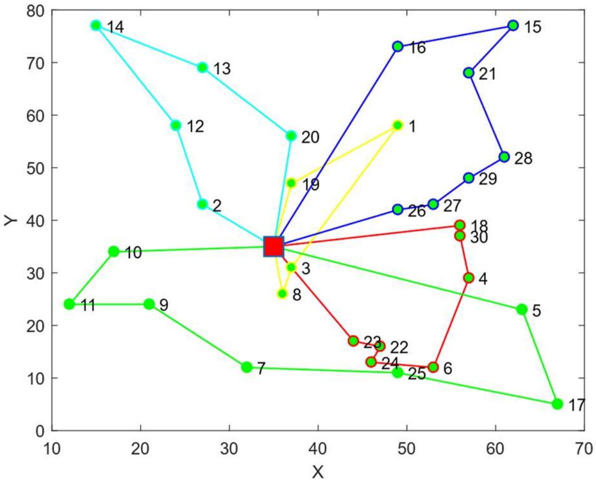

Figure 2. Vehicle routing route drawn from the optimal result

6. Conclusion

This paper proposes a joint scheduling problem for perishable food production and distribution based on the goal of minimizing the total cost of distribution, which considers delivery time windows, distribution routes, order production sequencing and production personnel scheduling. For this complex problem, this paper combines the characteristics of the model and uses the genetic algorithm to solve the constructed model. The experimental results show that the genetic algorithm designed can quickly obtain a relatively optimal joint scheduling scheme for the production and distribution of perishable food, which verifies the validity of the model, and has certain advantages and reference value for fresh food e-commerce enterprises in the collaborative decision-making of production and distribution plans.

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