

Research on the Application of Linear Programming Model Based on Ant Colony Algorithm in Decision Making of Superstores

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Abstract. In fresh food superstores, the freshness period of general vegetables is relatively short, and the quality deteriorates with the increase of the sales time. In addition, most of the varieties can not be re-sold on the next day if they are not sold on the same day. In this paper, under the premise of ensuring the maximization of supermarket revenue, the corresponding linear programming model is established, while introducing the heuristic algorithms ant colony algorithm to provide decision-making recommendations for supermarkets to replenish vegetables and pricing problems.

Keywords: linear programming model, ant colony algorithm, heuristic algorithm.

1. Introduction

In fresh food superstores, the freshness period of general vegetable commodities is relatively short, and the quality deteriorates with the increase of sales time. Therefore, superstores usually replenish their stocks every day according to the historical sales and demand of each product. Merchants have to make replenishment decisions for each vegetable category on the same day without knowing the specific products and purchase prices. Reliable market demand analysis [1-2] is particularly important for replenishment and pricing decisions. From the demand side, the sales volume of vegetable goods tend to have a certain correlation with the time; from the supply side, the supply of vegetable varieties from April to October is more abundant, the limitations of the sales space of the superstore makes the reasonable sales mix has become extremely important. In order to determine the sales plan of vegetables in supermarkets, this paper establishes a linear programming model based on the data related to vegetable sales in the previous three years [3], introduces a heuristic algorithm to improve the general ant colony algorithm [4], and solves the linear programming model by using the improved ant colony algorithm [5], and then finally arrives at the decision-making suggestions for vegetable replenishment and pricing.

2. Modeling

2.1. Establishment of linear programming model

Assuming that the number of vegetable singles is controlled between 27-33, when selecting vegetable singles, the 0-1 variable is introduced, which is defined as follows for whether the vegetable singles are sold or not:

$$\begin{cases} 0, & \text{Vegetable } i \text{ not on the shelf on day } j \\ 1, & \text{Vegetable } i \text{ on the shelf on day } j \end{cases} \quad (1)$$

Thus, the first constraint inequality condition is listed as follows:

$$27 \leq \sum_{i=1}^n q_i \leq 33 \quad (2)$$

Where, denotes the number of types of vegetable single product.

According to the market requirements, the ordering quantity of all kinds of vegetables satisfies the minimum display quantity constraint of 2.5kg, and this paper assumes that the ordering quantity of a single product of vegetables is e_i ($j=1,2,\dots,n$), thus obtaining the second constraint inequality condition as follows:

$$e_i < 2.5 \quad (3)$$

By organizing the vegetable sales data to obtain a data file of sales volume and cost-plus pricing for the statistical timeframe of available vegetable items between June 24 and 30, 2023; and then processing the data and calculating a linear regression relationship between the total monthly volume of sales for each vegetable item and the cost-plus pricing, the equation constraints are shown below:

$$y_i = a_i Q_i + c_i \quad (4)$$

where a_i, c_i denotes the constant of the linear regression relationship for the i th vegetable, y_i denotes the cost-plus pricing of the i th vegetable, and Q_i denotes the total monthly volume of sales of the i th vegetable.

For the calculation of profit, this paper refers to the concept of cost-plus [6] to list the expression of cost-plus pricing for a single product of vegetables:

$$y_i = (1 + w_i) c_i \quad (5)$$

where w_i denotes the profit of the i th vegetable and c_i denotes the cost of the i th vegetable purchase.

The profit earned by the superstore is expressed as the sum of the products between its sales volume and the values of its 0-1 variables. Therefore to maximize the profit of the superstore, the objective function of the linear programming model is expressed as follows:

$$\max \sum_{i=1}^n w_i Q_i q_i \quad (6)$$

Based on the above, the expression of the linear programming model for profit maximization of the superstore is determined as follows:

$$\begin{aligned} & \max \sum_{i=1}^n w_i Q_i q_i \\ & \begin{cases} 27 \leq \sum_{i=1}^n e_i \leq 33 \\ e_i \leq 2.5 \\ y_i = a_i Q_i + c_i \\ y_i = (1 + w_i) c_i \\ i = 1, 2, \dots, n \end{cases} \end{aligned} \quad (7)$$

2.2. Ant colony algorithm

The large size of the data makes it impossible to solve the linear programming model by conventional algorithms. In order to save time and increase efficiency, the model is solved using ant colony algorithm [4][5][7].

2.2.1 Principle of the algorithm

Ant colony system is a meta-heuristic algorithm first proposed by Dorigo, Maniezzo et al. in the 1990s. It is characterized by random operators and other operators, fast convergence, and fast iteration

of the final result. The principle of the ant colony algorithm is inspired by the natural phenomenon of ants moving. When there is an obstacle on the ants' path to the food site, the path to the food site is divided into two, and the ants will go around the obstacle and continue to move forward. Initially, the number of ants traveling on both paths is the same, but as time passes, the number of ants traveling on the shorter path increases, so more pheromones of ants are left on the shorter path. The increasing number of pheromones on the shorter path will cause more ants to choose the shorter path, which in turn will cause fewer ants to choose the longer path. In the end the ants basically take the shortest path and ignore the longer path.

2.2.2 Steps for the implementation of the Ant Colony Algorithm model

The ACO algorithm is transformed into a TSP problem with n cities to illustrate the implementation steps of the graph search ACO algorithm[8]. Given a TSP problem with n cities, the number of artificial ants is m and the behavior of each artificial ant follows the following pattern:

- The next path is selected with a corresponding probability based on the pheromone concentration on the path.
- No longer picks the path it has already traveled in this loop as the next step and uses a data structure to control this.
- When a cycle is completed, the appropriate concentration of pheromone is released based on the entire length of the path, and the pheromone concentration is updated for the path traveled.

Suppose that $\lambda_{ij}(t)$ denotes the pheromone size at generation t of the search cycle, on the connecting arc (i, j) . At the beginning of the search, the pheromones distributed on each path are equal, i.e., $\lambda_{ij}(0) = C$ (constant). The magnitude of the pheromone value is then varied at each generation of the search cycle by the pheromone evaporation effect and the pheromone enhancement effect brought about by the search of some individual ants. During the search process, the ant individual A_k (k denotes the number) decides the direction of advancement based on the amount of information on each path, and the probability P_{ij}^k of transferring to the next node at each node is jointly determined by the pheromone $\lambda_{ij}(t)$ and the amount of locally inspired information δ_{ij} . The latter is a function of the length of the connecting arc and is generally defined as $\delta_{ij} = \frac{1}{d_{ij}}$. Therefore, the individual ants are biased by the transfer probability to select the city with the shortest connectivity arc and high pheromone value as the next node to be searched.

At generation t of the search cycle, the probability $P_{ij}^k(t)$ that ant individual A_j moves from city i to city j is defined as:

$$P_{ij}^k(t) = \begin{cases} \frac{\lambda_{ij}^\alpha(t) \delta_{ij}^\beta(t)}{\sum_{r \in W^k} \lambda_{ij}^\alpha(t) \delta_{ij}^\beta(t)}, & j \in W^k \\ 0, & \text{Others} \end{cases} \quad (8)$$

In the formula, W^k is the city that ant k is allowed to choose next; α, β denote the information accumulated by the ant during its movement and the different roles played by the heuristic factors in the ant's choice of path, respectively.

Different from the actual ant colony, the graph search ant colony algorithm has a memory function, and each individual ant can memorize the cities it has traveled. As time goes by, the pheromone left behind gradually fades away, and the parameter indicates the degree of information fading away. After n cities are searched, the ants complete a cycle, and the amount of information on each path should be adjusted according to the following equation:

$$\lambda_{i,j}(t+1) = \rho \lambda_{i,j}(t) + (1-\rho) \Delta \lambda_{i,j}(t) \quad (9)$$

$$\Delta\lambda_{i,j}(t) = \begin{cases} \frac{Q}{L_k}, & \text{If the } k\text{th ant passes through the arc } (i, j) \text{ in this cycle} \\ 0, & \text{Others} \end{cases} \quad (10)$$

In the formula, Q denotes a constant; L_k denotes the length of the path taken by the k th ant in this cycle.

Depending on the specific algorithm, $\lambda_{i,j}^k(t)$, $\Delta\lambda_{i,j}^k(t)$ and $P_{i,j}^k(t)$ can be expressed in different forms, depending on the specific problem.

The step-by-step diagram of the ant colony algorithm implementation is shown in Fig.1.

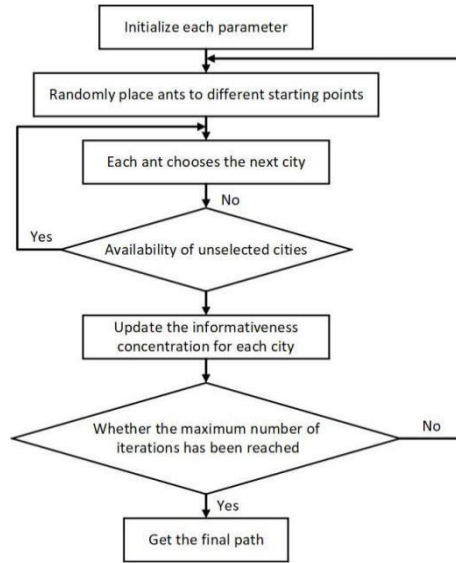


Fig. 1 Steps in the implementation of ACO algorithm

3. Results

The vegetable sales data obtained from the collation were substituted into MATLAB for the calculation of ant colony algorithm. On the basis of the traditional two-dimensional ant colony algorithm, the two-dimensional algorithm is transformed into a three-dimensional algorithm [9] by means of the heuristic function [10], which improves the speed of convergence and avoids the disadvantage of the traditional algorithm that is easy to fall into the local optimal solution. The results obtained in the most are shown in Fig. 2 and Fig. 3 (the selected data are from <http://www.mcm.edu.cn/>):

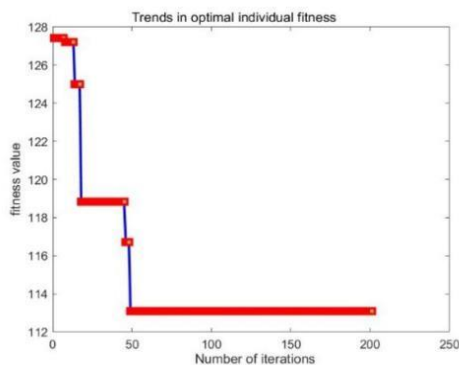


Fig. 2 Ant colony algorithm 3D path

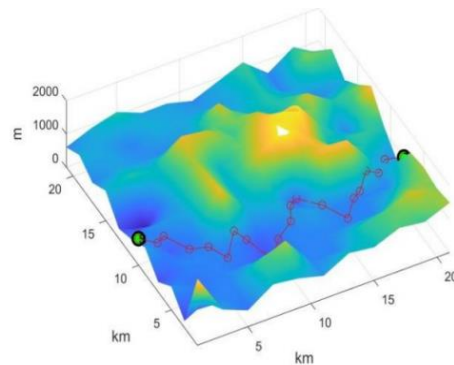


Fig. 3 Variation of optimal individual fitness of ACO algorithm

The replenishment quantity and pricing strategy of individual items of saleable vegetables were calculated by ant colony algorithm. Due to the high number of individual items of vegetables, the data of 14 randomly selected vegetables are shown in Table 1:

Table. 1 Computational decision-making results of ACO algorithm

Vegetable Single Name	Vegetable replenishment(kg)	Percentage change in price
Round eggplant (2)	4.017	38.90%
Xixia mushroom (1)	17.722	47.44%
Wuhu green peppers (1)	26.922	58.52%
Zijiang beetroot	2.126	59.72%
Fishbulb (portions)	1.000	63.47%
Honghu lotus root (Powdered lotus root)	7.000	71.16%
Duo of crab mushroom and White jade mushroom	1.000	85.39%
Yunnan oilseed rape(portions)	9.000	94.32%
Yunnan lettuce (servings)	13.000	98.46%
Baby bok choy	3.169	111.76%
Millet peppers (servings)	19.000	118.59%
Small bok choy (1)	5.319	127.21%
Yunnan lettuce	10.441	134.26%
Apricot mushroom (2)	3.156	138.76%

In order to more visually compare the changes in the prices of individual vegetable items, this paper presents a line graph of the changes in the prices of 14 randomly selected vegetables, as shown in Fig.4:

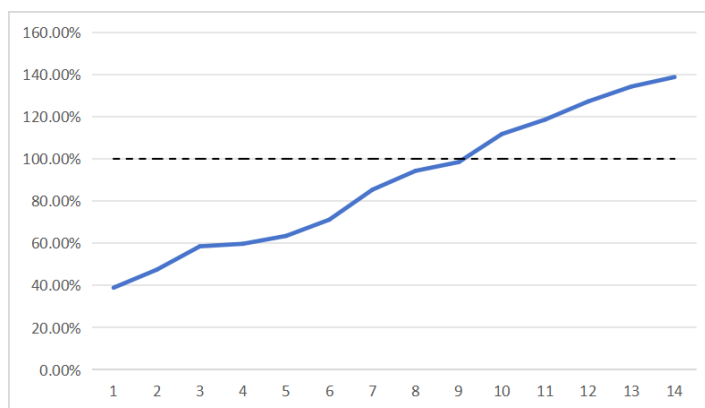


Fig. 4 Line graph of price changes of individual vegetable items

(1-Round eggplant(2), 2-Xixia mushroom(1), 3-Wuhu green peppers(1), 4-Zhijiang beetroot, 5-Fishbulb(portion), 6-Honghu lotus root (Powdered lotus root), 7-Duo of crab mushrooms and White jade mushrooms, 8-Yunnan oilseed rape(portions), 9-Yunnan lettuce(servings), 10-Baby bok choy, 11-Millet peppers(servings), 12-Baby bok choy(1), 13-Yunnan lettuce, and 14-Apricot mushrooms(2))

As can be seen from Fig.4, as far as these 14 kinds of vegetables were concerned, the prices of only 5 kinds of vegetables were increasing, while the prices of other vegetables were decreasing, and the ratio of the number of popular vegetable items was about 35.71%. For example, the proportion of change in the price of apricot mushrooms (2) was 138.76%, with the highest increased; the proportion of change in the price of round eggplant (2) was 38.90%, with the highest decreased, which indicated that the number of popular vegetable singles accounted for a relatively small percentage among vegetables. Therefore, when supermarkets replenish and price vegetables, they should focus on observing and locking the most popular vegetable items, increase the replenishment of such vegetables and raise the price appropriately; for the unpopular vegetables, supermarkets should reduce the replenishment quantity, and at the same time, reduce the price of such vegetables according to the situation, in order to maximize the profitability of the purpose.

4. Conclusions

In this paper, for the problem of vegetable replenishment and pricing in superstores, a linear programming model is established with the goal of maximizing the profit of superstores, with the linear relationship between cost-plus pricing and sales volume and profit margin, the limit of the number of vegetable single products and the minimum number of columns and columns of vegetable single products as the constraints, and the innovative use of ant colony algorithm to solve the model. This paper kicks out the noise data by organizing the original data, which not only avoids the influence of abnormal data on the decision-making results, but also makes the decision-making results more accurate. Compared with the traditional two-dimensional ant colony planning model, the heuristic function introduced in this paper transforms the two-dimensional algorithm into a three-dimensional algorithm, which improves the speed of convergence, and avoids the disadvantages of the traditional algorithm that is easy to fall into the local optimal solution. For example, among the randomly selected vegetable items, the replenishment quantities of baby bok choy (1), Yunnan lettuce, and apricot mushrooms (2) are 5.319kg, 10.441kg, and 3.156kg, respectively, and the proportions of the price changes are 127.21%, 134.26%, and 138.76%, respectively.

When replenishing and pricing vegetables, supermarkets should focus on observing and locking the most popular vegetable items, increase the replenishment of such vegetables and raise the price appropriately; for unpopular vegetables, supermarkets should reduce the replenishment volume and lower the price of such vegetables according to the situation to maximize the profit.

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