Optimization of vegetable commodity pricing based on particle swarm algorithm and sparrow search algorithm

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Abstract. With the improvement of people's living standards, small and medium-sized supermarkets have become important places for people to buy groceries in their daily lives due to their complete range of product categories, guaranteed quality, and accessibility to residential areas. However, due to the characteristics of vegetables being greatly affected by weather, difficult to store, and having a large regional preference, most small and medium-sized supermarkets need to purchase them daily and maximize profits within limited sales space. Therefore, building a model to meet the needs of short-term pricing and replenishment strategies for small and medium-sized businesses has important practical significance. This article establishes a multi-objective programming model based on historical sales data of supermarkets, and uses sparrow search algorithm and particle swarm optimization algorithm to improve the accuracy of results, making scientific and reasonable strategic planning for small and medium-sized supermarkets to purchase goods.

Keywords: Vegetable Products, Pricing Replenishment Strategy, Particle Swarm Optimization Algorithm, Sparrow Search Algorithm, Planning Model.

1. Introduction

In recent years, with the development of the economy and society, and the improvement of the education level of residents, the demand for fresh vegetables has also continued to grow[1]. Healthy diet has become a common concern among people. People no longer only pursue affordable food prices, but also incorporate food quality, safety, and freshness into their "food basket"[2]. Supermarkets are shopping places that retail essential goods to consumers, with daily necessities, food, and fresh products as their main business products[3]. Compared to agricultural markets, fresh vegetables in supermarkets have traceable sources, controllable quality, and can effectively meet the consumption standards of current consumers. However, due to the biological characteristics of fresh vegetables themselves, they are greatly affected by weather, difficult to store, and have a large regional preference[4]. This makes the production, transportation, and sales of vegetables more difficult. Fresh vegetable sales terminals need to have more scientific and comprehensive pricing and replenishment strategies.

Yu et al.[5] focuses on the supply chain, regards service level as a function of freshness, and demand as a function of freshness and price. It studies the pricing and service level decision-making issues of fresh agricultural products. Wang Shuyun et al[6]. studied the coordination and optimization problem of the supply chain in a three-level cold chain inventory optimization model, taking into account the freshness of goods and quantitative loss. Based on a two-dimensional analysis of price fluctuation factors, Morissa[7] uses Python intelligent data fitting to intelligently predict vegetable prices. However, existing research is mostly based on the analysis of large supermarkets with complete refrigeration and preservation systems, while there is a lack of research on small and medium-sized supermarkets that are more numerous and closer to people's lives. Compared to large supermarkets and agricultural markets, small and medium-sized supermarkets meet the shopping needs of residents within walking distance, improving the convenience of residents' lives. Therefore, studying scientifically complete pricing and replenishment strategies from the perspective of small and medium-sized supermarkets has important practical significance.

Small and medium-sized supermarkets are constrained by cost control and scale, and their equipped refrigeration and preservation capabilities are low, resulting in limited sales space. In order to ensure the freshness of fresh vegetables, daily replenishment is necessary. By fully utilizing sales space, a reasonable sales combination is selected to maximize supermarket profits. Due to the small service scope and relatively fixed service group of small and medium-sized supermarkets, decisions can be planned based on historical sales data of goods to make reasonable and efficient strategies. This article establishes a multi-objective programming model based on examples, and optimizes the solution through sparrow search algorithm and particle swarm optimization algorithm, comparing and evaluating the advantages and disadvantages of the algorithm.

2. Theoretical basis of the model

2.1. Multi objective programming model

Multi objective programming (MOP) is an analytical decision-making model that combines qualitative and quantitative analysis to consider multiple factors constrained by multi-objective combinations[8]. Its basic model includes two parts: objective function and constraint conditions. The basic steps are variable construction, objective function determination, and simultaneous constraint conditions.

2.2. Sparrow search algorithm

Heuristic algorithms have strong search capabilities and can use computers to quickly iterate to obtain optimal solutions, making them suitable for complex optimization problems. Sparrow search algorithm is an emerging heuristic optimization algorithm that solves optimization problems by simulating the behavior of sparrows while foraging, with high efficiency and accuracy[9].

The operation process involves initializing the algorithm parameter population, evaluating the fitness function, selecting, crossover, and mutation, updating the population, evaluating the early warning system, determining termination conditions, and outputting results.

2.3. Particle Swarm Optimization

Particle Swarm Optimization (PSO), also known as Particle Swarm Optimization (PSO), was proposed by American scholars Kennedy and Eberhart. Its basic idea originated from simulating bird foraging behavior and evolved into a search algorithm based on group collaboration[10].

The particle swarm optimization algorithm first needs to define the parameters of the particle swarm optimization algorithm, initialize the parameters of the particle swarm, as well as the position and velocity of each particle, calculate the fitness value based on the fitness function, and record the historical optimal value p_{best} and the global optimal value g_{best}.

Update the velocity and position of each particle through iteration, using the following formula:

$$v_{ij}(t+1) = v_{ij}(t) + c_1 r_1 (p_{best}(t) - x_{ij}(t)) + c_2 r_2 (g_{best}(t) - x_{ij}(t)) \tag{1}$$

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \tag{2}$$

In each iteration, calculate the fitness value of each particle and compare it with p_{best}. If it is better, it is used as the latest p_{best} until the preset maximum number of iterations is reached, outputting the optimal solution.

3. Model establishment and solution

This article focuses on establishing and solving models based on existing data.

3.1. Data sources

Data source: http://www.mcm.edu.cn/

Due to the need to obtain the available varieties of vegetable items for June 24-30, 2023, we added up the sales volume of various vegetable items from June 24th to 30thp, and the vegetable items with a total sales volume of 0 were excluded to obtain the available varieties of vegetables. A total of 38 available varieties were obtained as the basic data.

***Step 1:* 0-1 Planning Model**

Due to a total of 38 available varieties, which is greater than the maximum required total number of single products, a 0-1 programming model is used to introduce decision variable c_i to indicate whether to order the i th type of vegetable single product. If $c_i = 1$, it means ordering the i th category of vegetable items; If $c_i = 0$, it means that the i th category of vegetable items will not be ordered.

***Step 2:* Multi objective programming model**

(1) Establish objective function

According to the requirements of the question, Question 2 has two objective functions:

Try to meet the market demand of various categories of vegetables, that is, minimize the difference between the sales volume and replenishment volume on July 1st, that is:

$$\min h = \sum_{j=1}^{6} \left| \sum_{i=1}^{m} k_{ij} - s_j \right| \tag{3}$$

Among them, h represents the difference between sales volume and replenishment volume, k_{ij} represents the replenishment volume of the i th vegetable item in the j rd vegetable category, m represents the number of items in the j th vegetable category, and s_j represents the sales volume of the j th vegetable category.

1. The maximum profit for supermarkets can be obtained based on the replenishment volume and pricing strategy of products provided in Model 2, which is:

$$\max z = \sum_{i=1}^{38} c_i (p_i * s_i + k_i * l_i) \tag{4}$$

Among them, z represents the profit of supermarkets, p_i represents the daily sales unit price of the j rd category of vegetables, s_i represents the daily sales volume of the i th category of vegetables, k_i represents the daily replenishment volume of the i th category of vegetables, and l_i represents the daily wholesale price of the i th category of vegetables.

(2) Establish constraints

1. The number of sellable items should be controlled between 27-33, that is:

$$27 \le \sum_{i=1}^{38} c_i \le 33 \tag{5}$$

Among them, c_i is the decision variable, indicating whether to order the i nd category of vegetable items. If $c_i = 1$, it means ordering the i th category of vegetable items; If $c_i = 0$, it means that the i th category of vegetable items will not be ordered.

2. The minimum display quantity for each ordered item is 2.5 kilograms, which is:

$$c_i k_i \geq 2.5 \tag{6}$$

Among them, c_i is the decision variable, indicating whether to order the i nd category of vegetable items. If $c_i = 1$, it means ordering the i th category of vegetable items; If $c_i = 0$, it means that the i th category of vegetable items will not be ordered. k_i represents the replenishment quantity of the i th category of vegetable items.

(3) Multi-objective programming model

In summary, multiple planning models can be obtained:

$$\min h = \sum_{j=1}^{6} \left| \sum_{i=1}^{m} k_{ij} - s_j \right| \tag{7}$$

$$\max z = \sum_{i=1}^{38} c_i (p_i * s_i + k_i * l_i) \tag{8}$$

$$s.t. \begin{cases} 27 \leq \sum_{i=1}^{38} c_i \leq 33 \\ c_i k_i \geq 2.5 \end{cases} \tag{9}$$

3.2. Solving process

Table 1 shows the entire solution process, as follows:

Table 1 MATLAB Solving the process table

Solve the process table
I nput: Import the sales volume, sales price, wholesale price and other data of each single product
Step 1: Data screening, obtained 27-33 major single products
S tep2: Calculate the average value of the historical data to replace the demand of the six major vegetable categories on July 1,
Step 3: Set the initial parameters of the particle swarm algorithm
S tep4: Optimize by using the particle swarm algorithm
Step 5: Set the initial parameters of the sparrow search algorithm
Step 6: Seek optimization through the sparrow search algorithm
Step 7: Comprehensive comparison of the solution quality of the two algorithms, and the high efficiency of the solution
O utput: Optimal single-product replenishment volume and pricing strategy

4. Results

4.1. Optimal replenishment pricing decision

Substituting the data, the optimal pricing and replenishment of vegetable items were obtained through model solving and screening, as shown in Table 2:

Table 2. Details of screening of vegetable items and replenishment pricing

category	Single name	Supplemental quantity	ullage	sales volume	retail price	income	prime cost	profit
edible fungi	Xixia Flower Mushroom (1)	2.50	0.27	2.23	23.88	53.26	38.96	14.30
Flowers and leaves	edible amaranth	28.62	5.30	23.32	5.33	124.30	43.85	80.45
Flowers and leaves	bengal dayflower herb	16.16	2.20	13.96	8.73	121.83	28.04	93.79
Flowers and leaves	Shanghai green	26.98	3.89	23.08	7.15	164.99	102.35	62.64
Flowers and leaves	Malabar spinach	57.00	4.34	52.66	8.61	453.17	107.08	346.09
Solanum	Purple eggplant (2)	60.96	3.70	57.26	4.87	279.02	199.69	79.33
Flower vegetables	broccoli	72.54	6.72	65.82	11.41	751.33	542.42	208.91
Aquatic rhizomes	Net lotus root (1)	31.72	1.76	29.96	13.63	408.36	327.18	81.18
Flowers and leaves	baby Chinese cabbage	89.83	2.23	87.60	5.17	453.31	399.51	53.80
Flowers and leaves	Sweet potato tip	4.95	0.42	4.54	4.30	19.51	6.64	12.86
Aquatic rhizomes	ling	7.21	0.69	6.52	13.70	89.37	52.71	36.66
Aquatic rhizomes	Red lotus root belt	3.65	0.61	3.04	8.70	26.46	17.54	8.92
Flowers and leaves	Milk cabbage	18.95	2.97	15.98	5.17	82.58	48.33	34.25
Pepper class	Wuhu Green Pepper (1)	63.34	3.61	59.73	5.39	322.20	245.09	77.11
Solanum	Long-term eggplant	17.55	1.21	16.34	11.66	190.55	122.29	68.26
Flowers and leaves	Small vegetables (1)	28.39	2.93	25.46	4.68	119.07	75.80	43.27
Flowers and leaves	Yunnan Lettuce (portions)	156.16	14.73	141.43	5.29	747.65	537.82	209.83
Flowers and leaves	Yunnan oillettuce (portion)	42.99	4.05	38.93	4.85	189.02	122.84	66.18
Flowers and leaves	Spinach (part)	52.93	4.99	47.94	5.60	268.44	199.79	68.65
Pepper class	Millet pepper (part)	117.30	11.06	106.24	5.04	535.45	247.67	287.79
edible fungi	Cordyceps flower (part)	22.76	2.15	20.61	3.63	74.88	58.40	16.48
Pepper class	Small wrinkle skin (part)	20.49	1.93	18.56	3.82	70.90	48.00	22.90
Pepper class	Screw pepper (part)	28.86	2.72	26.14	6.46	168.82	133.55	35.27

Pepper class	Ginger, garlic, millet and pepper combination (small portion)	16.29	1.54	14.75	5.89	86.87	37.81	49.05
Flower vegetables	Zhijiang green stem scattered flowers	12.74	1.20	11.54	11.09	127.87	94.45	33.43
edible fungi	Bisporus mushroom (box)	31.76	0.06	31.70	5.18	164.19	109.32	54.88
Pepper class	Green and red hang pepper combination (parts)	28.65	2.70	25.95	4.76	123.61	102.57	21.03
Pepper class	Red pepper (2)	15.27	1.44	13.83	16.93	234.11	201.71	32.40
edible fungi	Flammulina mushroom (box)	73.26	0.33	72.93	1.87	136.03	106.07	29.96

The pricing strategy is that the sales unit price is equal to the price elasticity coefficient multiplied by the change in sales volume plus the previous sales unit price

The final profit obtained is 2237.03, and the difference between replenishment and demand is 130.69.

4.2. Algorithm performance evaluation

4.2.1 Pareto Frontier Analysis

Figure 1 is a Pareto diagram of the merged solution set of two algorithms, as shown below:

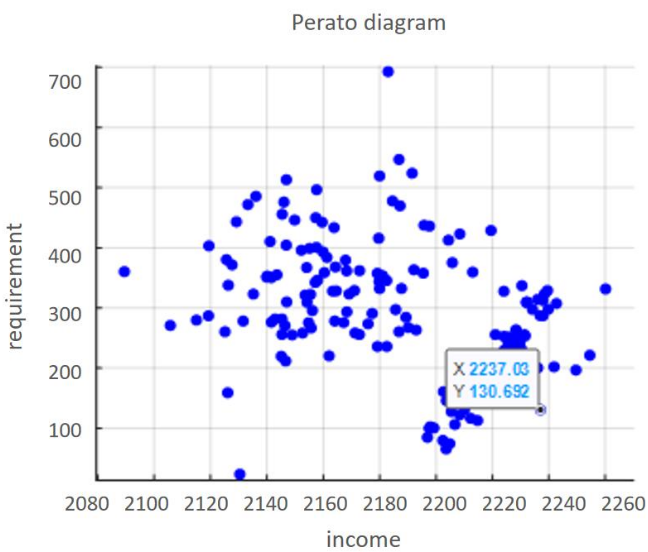

Figure 1 Pareto diagram of merging solution sets

The above figure provides information about the feasible domain of the problem. All the points above indicate finding solutions that satisfy all objectives under constraints. From the above figure, it can also be seen that the diversity of feasible solutions is relatively high. This is because this problem combines the solution set of particle swarm optimization algorithm and sparrow search algorithm, which can better ensure the quality of solutions. At the same time, the best solution selected through fast non dominated sorting combined with crowding degree sorting is the solution shown in the graph with specific data. It can be seen from the graph that this solution is indeed more reasonable than other solutions.

4.2.2 Result evaluation

The quality of the solution set can be measured by using indicators such as non dominated sorting distance, crowding degree, and hyper volume. These indicators can be compared by calculating the average or total value of the solution set generated by each algorithm. Figure 2 shows the calculated indicator data, as shown below:

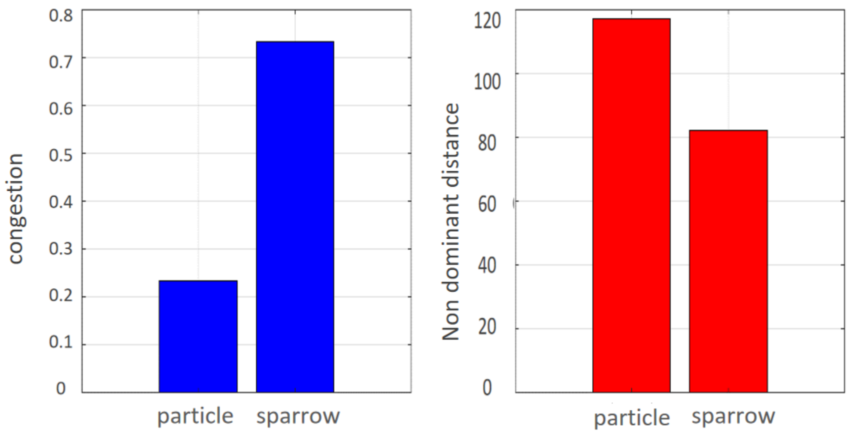

Figure 2 Comparative indicator data

According to the above figure, it can be seen that the particle swarm algorithm performs better in non dominated distance and is more inclined to find solutions closer to the optimal solution. However, the sparrow search algorithm performs well in terms of crowding and maintains diversity of understanding.

5. Conclusion

This article aims to achieve the goal of maximizing profits by utilizing historical data from supermarkets as a foundation. By limiting the variety of replenished goods and making reasonable predictions about product combinations, it ensures effective inventory management. In order to optimize pricing strategies, the article introduces the Sparrow Search Algorithm and Particle Swarm Optimization Algorithm, and utilizes MATLAB software for quantitative analysis to determine the optimal prices and replenishment quantities. This model is not only practical but also further improves the accuracy of results through the application of optimization algorithms. The following conclusions are drawn: when calculating the optimal pricing strategy, it is necessary to consider multiple factors. Firstly, it is important to meet the market demand for various categories of vegetables, i.e., minimizing the difference between market sales and replenishment quantities. Secondly, meeting the demand for selected categories of vegetables can maximize the profits of supermarkets. Therefore, this study provides strong support for the digital scientific management, operation, and development of small and medium-sized supermarkets, and is expected to achieve significant results in practical operations.

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