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Research on vegetable sales decision-making based on single-objective nonlinear optimization and genetic algorithm

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Abstract: With the continuous upgrading of consumers' consumption level and consumption demand, the market scale of fresh food superstores is growing year by year. Facing the competitive market environment, merchants need to develop reasonable replenishment and pricing strategies by matching the supply and demand of commodities, so as to promote the maximization of superstore revenue. In this paper, based on the historical sales data of vegetables, polynomial regression is chosen to predict the sales demand based on the analysis results of sales data, and further predict the daily sales volume of six vegetable categories in the coming one-week period. Then, a single-objective nonlinear optimization model related to the total sales volume of each vegetable category and the cost-plus pricing is established, and the optimal solution and optimal value are found out by using genetic algorithm according to the constraints. Finally, the total amount of replenishment and the optimal pricing strategy for each vegetable category are derived.

1. Introduction

In recent years, fresh food supermarkets have been developing rapidly in major cities by virtue of their fresh and high-quality commodities and convenient and affordable business shopping mode. Due to the short shelf life and rapid deterioration of a large number of vegetable categories in fresh food supermarkets, the loss and waste of inventory is very serious. In order to ensure that supermarkets can sell fresh vegetables every day, fresh supermarkets usually need to restock according to the previous sales of vegetable categories and demand. In fresh food supermarkets, vegetables are usually purchased in the early hours of the morning, so merchants usually need to make replenishment decisions for vegetables when the products and unit prices are unknown. With the information provided by the demand and supply sides, reasonable replenishment and pricing strategies are developed to promote the maximization of supermarket revenue.

In order to formulate a reasonable replenishment and pricing strategy, we found that a large number of scholars have conducted research and discussion on this issue. For example, some scholars have derived the optimal raw material ordering and forwarding plan under different constraints based on the optimal ordering and forwarding model of multi-objective optimization and genetic algorithm for the "Ordering and Transportation of Raw Materials in Manufacturing Enterprises", and then finally predicted the production capacity enhancement of the enterprise and the future ordering and forwarding plan through the above conclusions (Yumeng Zhang, Yi Su, Yongqi Wu, and Jiaming Zhu, 2022)[1-3], which is the first time that a research and development program has been developed for a manufacturing enterprise in China.For the replenishment and pricing strategy of fresh products such as vegetables, Qiao Xue proposed a joint replenishment pricing strategy, taking into account the impact of price on demand and maximizing the average profit in an infinite time domain under the circumstance of declining quantity of fresh products, and maximizing the average profit in an infinite time domain. For the rational pricing of different fresh products, Liao Wenjing proposed that a joint optimization model of the logistics network can be constructed to optimize the delivery and dispatch time of agricultural products under the origin-collecting and distribution mode of fresh e-commerce, and the optimal pricing scheme can be derived from the model by solving the model through hybrid genetic algorithms (Liao Wenjing, 2023)[4-5], and the scholars, Ning Xiaoli, and Wang Fapo, took the distribution point of Nanyang Shunfeng Yancheng as an example, and used the mileage-saving method and genetic algorithm to carry out the optimal pricing scheme respectively.

Therefore, polynomial regression is chosen to predict the daily sales demand of the six types of vegetables in the coming one-week period. Then a single-objective nonlinear optimization model related to the total sales volume and cost-plus pricing of the six types of vegetable items is established, and the optimal solution is found using genetic algorithm based on the constraints to obtain the optimal strategy for vegetable sales decision.

2. Modeling and solving

2.1 Determine if a linear relationship exists

In this paper, the data of vegetable sales details come from the competition database (http://www.mcm.edu.cn/html_cn/node/). The database contains the commodity information of six vegetable categories distributed by a superstore; the correlation data between the sales flow details and wholesale prices of each commodity from July 1, 2020 to June 30, 2023 of the superstore; and the recent wastage rate data of each commodity. Taking the flower and leaf category as an example, a linear analysis of the data of six categories of vegetables of a fresh food superstore in June yields a correlation coefficient of -0.2525, a threshold of 0.7 is set, and according to Figure 1 below, it is concluded that the data do not show a linear relationship.

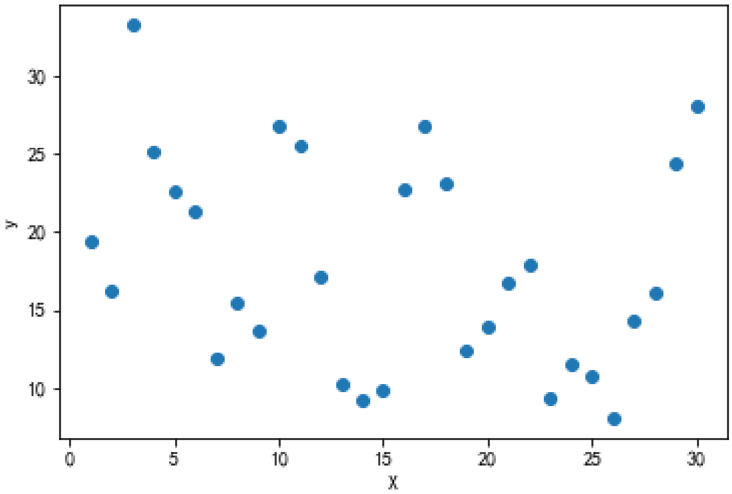

Figure 1: Floral leaves Scatterplot

2.2 Multinomial regression analysis

Polynomial regression is a regression analysis method used to model data with nonlinear relationships. It fits the data by introducing polynomial terms to adapt the model to more complex curve shapes. The general form of polynomial regression can be expressed as:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 \tag{1}$$

Y is the predicted sales volume, X is the characteristic variable (foliar, cauliflower, aquatic rhizome, eggplant, pepper, and edible mushrooms),β_0, β_1,...,$\beta_n$are the coefficients.

Based on the sales data analysis graph in Figure 2 below it can be seen that the six vegetable categories have a high variation in sales demand on June 3-4, June 10-11 and June 17-18 during these three time periods.

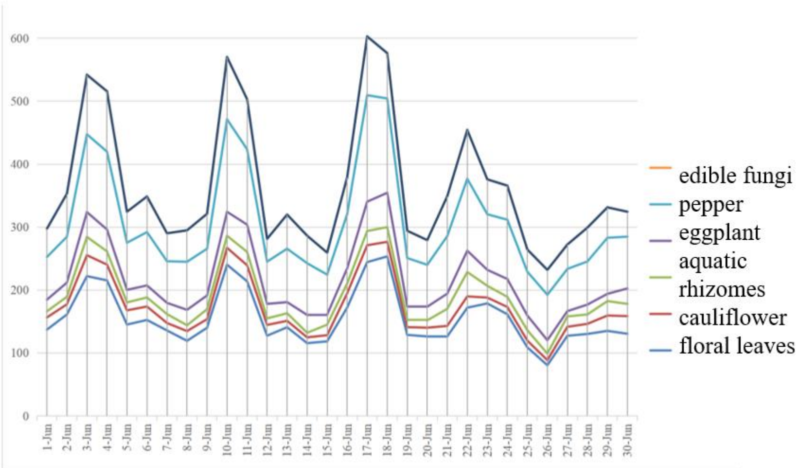

Figure 2: Sales Data Analysis Chart

The trend of daily sales volume of six vegetable categories in the coming week (July 1-7, 2023) is shown below in Figures 3 to 8. It can be concluded that the sales volume of Cauliflower and Aquatic Roots and Tubers will increase again in the coming week, while the sales volume of the other four types of vegetables will gradually decrease.

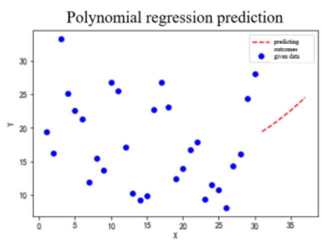

Figure 3: Cauliflower sales

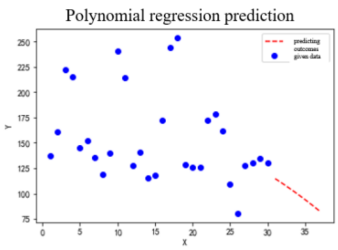

Figure 4: Floral leaves sales

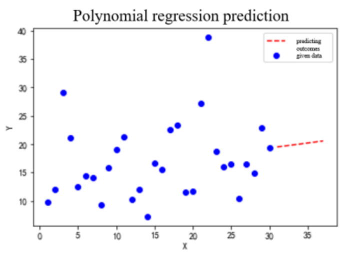

Figure 5: Aquatic sales

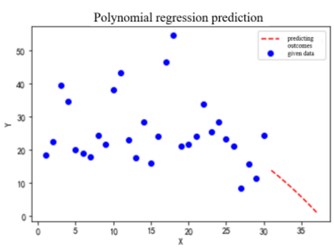

Figure 6: Eggplant sales

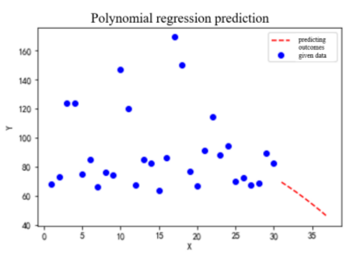

Figure 7: Pepper sales

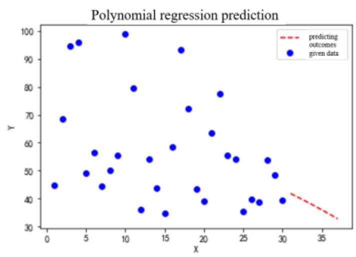

Figure 8: Edible fungi sales

The predicted values were obtained as shown in Table 1.

Table 1: Daily Sales Volume of 6 Vegetable Categories in the coming one-week time period

Date	Floral leaves	Cauliflower	Aquatic	Eggplant	Pepper	Edible fungi
1-Jul	114.773	19.435	19.519	13.833	69.345	41.831
2-Jul	109.896	20.145	19.692	11.983	65.874	40.416
3-Jul	104.807	20.911	19.866	10.032	62.205	38.961
4-Jul	99.506	21.733	20.041	7.978	58.338	37.468
5-Jul	93.993	22.612	20.217	5.822	54.274	35.936
6-Jul	88.268	23.548	20.394	3.564	50.013	35.936
7-Jul	82.332	24.540	20.573	1.205	45.554	32.753

2.3 Modeling single-objective nonlinear programming

Single-Objective Nonlinear Programming (NLP) is used to solve optimization problems containing nonlinear objective functions and nonlinear constraints. Then this problem uses Single-Objective Nonlinear Programming to find the maximum revenue of the superstore [6]. From the question, if we want to maximize the revenue of the fresh food superstore the formula is as follows:

a. Selling unit price = wholesale price+cost markup+additional cost for depletion;
b. Cost markup = cost price ×cost markup rate;
c. Depletion cost = original asset value ×depletion rate;
d. Cost price = wholesale unit price/1 + discount rate;
e. Total sales/sales unit price = sales demand;
f. Period-end inventory levels: = sales demand replenishment.

1) Depreciation expense:

$$W = C_i D_{i(t)}, \tag{2}$$

2) Gross sales revenue:

$$R = S_{i(t)} Q_{i(t)}, \tag{3}$$

3) Total cost:

$$TC = C_i Q_{i(t)} \tag{4}$$

4) Total profit:

$$TP = R - TC - W = Q_{i(t)} \lfloor S_{i(t)} - C_i \rfloor - C_i D_{i(t)} \tag{5}$$

5) Sales needs:

$$N_i = \frac{Q_{i(t)}}{S_{i(t)}} \tag{6}$$

6) Period-end inventory levels:

$$K_i = N_i - B_i \tag{7}$$

7) Cost price:

$$S_{i(t)} = H_{i(t)} + C_i X_i + C_i \cdot D_{i(t)} \tag{8}$$

8) Additive rate:

$$x_i = \frac{S_{i(t)} - H_{i(t)} - \frac{H_{i(t)}}{1 + D_{i(t)}} \cdot D_{i(t)}}{\frac{H_{i(t)}}{1 + D_{i(t)}}} \tag{9}$$

Constraint 1: cost plus ratio is greater than 0.
Constraint 2: Sales demand should be less than or equal to the total replenishment amount.
Constraint 3: Period-end inventory levels should be greater than zero to meet consumer demand.
Constraint 4: The cost price should be less than the wholesale price.
Finally the objective planning function is derived as:

$$maxTP = Q_{i(t)} \lfloor S_{i(t)} - C_i \rfloor - C_i D_{i(t)} \tag{10}$$

The constraints are:

$$ST \begin{cases} X_i > 0 \\ \frac{Q_{i(t)}}{S_{i(t)}} \leq B_i \\ K_i = N_i - B_i > 0 \\ 0 < C_i < H_{i(t)} \end{cases} \tag{11}$$

2.4 Solving the planning model

Genetic Algorithm (GA) is a heuristic algorithm for computer science and optimization problem solving. This method can be adopted when the additive rate is in a fixed discrete range of values and the above objective optimization model is a complex combinatorial optimization problem. The main steps of genetic algorithm include chromosome coding, population initialization, fitness function design, selection operation, crossover operation and mutation operation [7]. The solution process of genetic algorithm is shown in Figure 9.

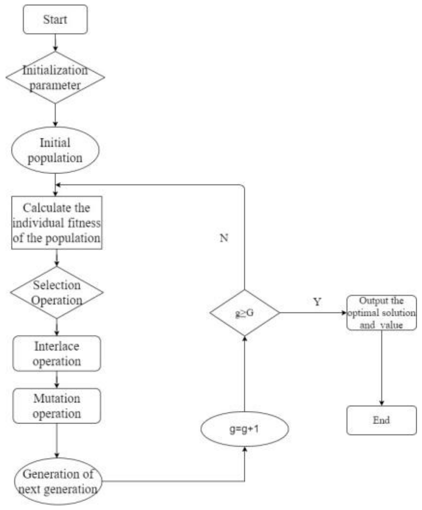

Figure 9: Flowchart of the basic genetic algorithm

Using genetic algorithm to solve the planning model solved the optimal solution: =19.182, =-15.712, =-15.712, =13.747, optimal value: =977.137.

By solving the model, the maximum returns of foliar, cauliflower, aquatic root, eggplant, pepper and edible mushroom were obtained as shown in Table 2:

Table 2: Total profitability of vegetables by category

Unit: Yuan

Date	Floral leaves	Cauliflower	Aquatic	Eggplant	Pepper	Edible fungi
1-Jul	97458.118	16247.417	14999.915	3005.180	56494.129	31935.165
2-Jul	87990.708	15879.543	15426.196	2319.565	51978.419	30785.089
3-Jul	78614.925	15412.114	15835.740	1694.794	47419.129	29606.387
4-Jul	69415.228	14882.153	16268.354	1143.931	42844.710	28399.600
5-Jul	60532.685	14259.605	16710.984	680.564	38284.967	27165.287
6-Jul	51904.265	13530.393	17163.796	318.762	33771.055	27108.630
7-Jul	43648.670	12679.805	17626.955	73.009	29292.225	24616.411

Using Python to solve the planning model, the cumulative daily replenishment totals for all the individual items in the six categories of foliage, cauliflower, aquatic roots and tubers, eggplants, peppers, and edible mushrooms for the coming week were obtained as shown in Table 3.

Cost prices were derived from wholesale prices as well as attrition rates, and then daily pricing strategies were derived from sales prices and cost prices. The average pricing for foliage (97 items) was $5.463, cauliflower (5 items) was $13.921, aquatic roots and tubers (19 items) was $15.231, eggplant (10 items) was $8.272, chili peppers (43 items) was $0.62, and edible mushrooms (72 items) was 10.082 dollars. Then, from July 1 to July 7, more leafy and chili pepper vegetable items should be sold to increase their prices and decrease the prices of aquatic root vegetables.

Table 3: Cumulative total daily replenishment of each individual item of vegetables for the coming week

Unit:kg

Date	Floral leaves	Cauliflower	Aquatic	Eggplant	Pepper	Edible fungi
1-Jul	2432.025	79.713	0.801	24.049	616.231	134.852
2-Jul	2247.783	86.507	0.846	18.310	551.652	129.424
3-Jul	2062.922	94.166	0.895	13.112	487.374	123.855
4-Jul	1878.461	102.762	0.948	8.583	424.020	118.157
5-Jul	1695.460	112.373	1.005	4.858	362.241	112.342
6-Jul	1515.024	123.082	1.066	2.076	302.722	111.289
7-Jul	1338.302	134.979	1.132	0.386	246.182	100.409

The predicted sales of the six vegetable categories from July 1-July 7, 2023 were fitted, and the results of the fit are shown in Figure 10. The goodness of fit is 0.52, which is a poor fit and can indicate that the model fails to capture the changes in the data well and there is a bias.

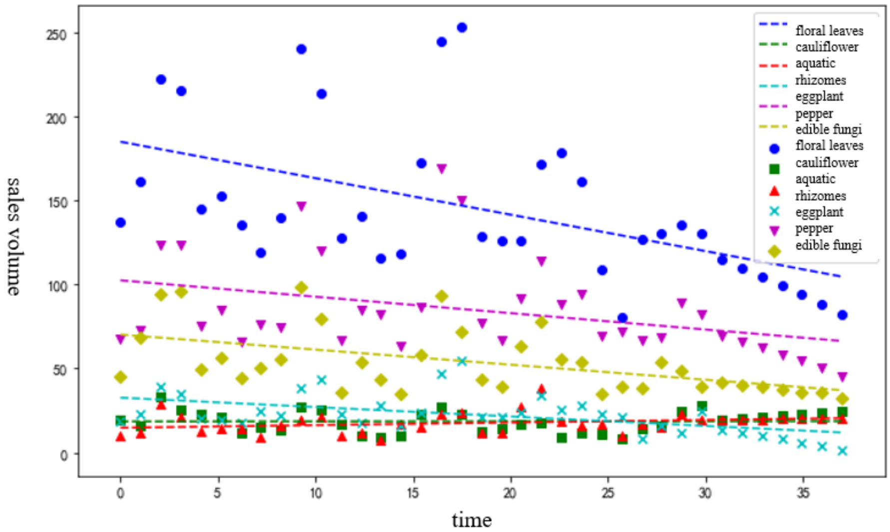

Figure 10: Fitting of sales volume data forecasts

3. Conclusions

China is a large agricultural country, and the output of many agricultural products is among the highest in the world. Data show that China's annual vegetable production has exceeded 50% of the world's total annual vegetable production. Reasonable matching of supply and demand of agricultural products has gradually occupied an important and unique position in the continuous development of China's national economy, which is directly related to the national economy and people's livelihood. In recent years, with the upgrading consumption level and consumption demand of consumers, the market size of fresh produce super market has been growing year by year. In the face of the competitive market environment, merchants need to match the supply and demand of commodities to develop a reasonable replenishment and pricing strategy, so as to promote the maximization of supermarket revenue. In this paper, based on the historical sales data of the selected vegetables, polynomial regression is chosen to predict the sales demand based on the analysis results of the sales data, and further predicts the daily sales volume of six vegetable categories in the coming one-week period. Then a single-objective nonlinear optimization model related to the total sales volume and cost-plus pricing of each vegetable category is established, and the optimal solution and optimal value are derived using genetic algorithm according to the constraints. Finally, the total amount of replenishment and the optimal pricing strategy for each vegetable category were derived, and it was found that more leafy and chili vegetables should be sold in the coming week to increase their prices, and the prices of aquatic root vegetables should be reduced. Through the testing and promotion of the model, it can be applied to major fresh food superstore platforms, so as to provide superstores with optimal replenishment and pricing strategies and promote the maximization of fresh food superstore revenues.

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