Research on pricing and replenishment decision of vegetable and fruit commodities-Based on nonlinear programming model and ARIMA time series forecasting

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Abstract. Due to the timeliness of vegetable and fruit sales, supermarkets generally supplement each product on a daily basis based on the past sales and demand of each product according to the specific situation. In order to make replenishment and pricing decisions for vegetables and fruits in commercial supermarkets, this paper considers cost, sales volume, supply and demand relationship and loss factors under profit maximization based on cost plus pricing method. Sales volume, cost plus pricing functions are defined, and seasonal ARMIA model is used for forecasting. The sales profit function and constraint conditions are established, and the nonlinear programming model is constructed to solve the problem to obtain the profit maximization scheme.

Keywords: Time series ARIMA, nonlinear programming model, forecasting model

1. Introduction

In the open market, the shelf life of fruits and vegetables is very short, and the time is inversely proportional to the quality and sales volume. Based on this replenishment decision is generally based on past sales and market demand, and cost-plus pricing method is selected for daily replenishment. There are many types of vegetables and fruits, and the producing areas are not the same. However, considering the freshness of vegetables and fruits and the peak sales period, the replenishment time is mostly in the early morning. It is necessary to supplement all varieties of vegetables and fruits on the day without knowing the commodity type and purchase price [1]. Both the demand and supply of fruits and vegetables are affected by time series. Due to the limitation of sales space, it is particularly important to properly match and predict commodities, and then establish a model to predict them [2].

In the study of maximizing the benefits of fresh products, Gu Sihong proposed that compared with static pricing, dynamic pricing strategy can help retailers improve profits and reduce waste [3] , Melissa proposed the concept of combining machine learning, time series and ARIMA model based on python for analysis of fresh product pricing strategy [4]. Fresh is a perishable product, Qiao Xue adopts heuristic parameter adjustment algorithm based on historical sales data to define the loss [5]. There are some problems in the circulation of fresh products, such as low degree of organization and lengthy transaction links. Sun Yuping proposed to improve the circulation of fresh products by improving the accuracy of sales forecast and the rationality of inventory allocation. ARIMA model is used to describe the linear relationship contained in the sales time series and NARX neural network is used to forecast[6]. For the pricing of fresh products, Lu Yajie proposed the value loss pricing method to conduct quantitative analysis on the freshness and value loss of fresh vegetables, established the pricing model of high-quality fresh vegetables in supermarkets based on value loss, and gave an example analysis [7]. From the perspective of retailers, Wu Lifang proposed to establish a retailer's multi-stage profit model and use the Hesser matrix to find the optimal pricing under the multi-stage condition when the retailer's profit is maximum [8]. Based on the background of new retail, this paper studies the pricing and inventory optimization of fresh products by using two-stage pricing and inventory strategy model. To obtain the new retail background, the two-stage pricing and inventory strategy model is used to study the pricing and inventory optimization of fresh products [9].

Based on the collected data, this paper considers the cost, sales volume, supply and demand relationship and depreciation factors under the cost-plus pricing method combined with profit maximization [10]. The pricing functions of sales volume and cost price were defined, and the future wholesale prices of vegetable categories were predicted using the seasonal ARMIA model. The sales profit function and constraint conditions are established, and the nonlinear programming model is constructed to solve the profit maximization scheme of each vegetable category in the supermarket in the next week.

Furthermore, we optimize the profit function and constraints based on the actual sales situation and requirements of the supermarket. On the premise of trying to meet the market demand for various types of vegetable products, we give the replenishment quantity and pricing strategy of a single product in the future, so as to maximize the profit of the supermarket.

2. Set up the price-sales function

In the actual operation process of commercial supermarkets, it is usually necessary to estimate the future daily replenishment total amount and pricing of each category and each vegetable single product. Since the analysis is conducted in units of vegetable categories, we first calculate the average daily sales pricing of vegetable categories and replace the cost-plus pricing with this pricing, which is calculated by the following formula:

$$\text{sale\_avg}_{i,d} = \frac{\sum_{j\in i} \text{sale}_{j,d} * \text{sale\_num}_{j,d}}{\sum_{j\in i} \text{sale\_num}_{j,d}} \quad (1)$$

The formula for calculating the total daily sales of each vegetable category is as follows:

$$sale\_num_{i,d} = \sum_{j\in i} sale\_num_{j,d} \quad (2)$$

For different categories, different functions are considered to fit the relationship between average sales price and total sales volume, including linear function, power function and logarithmic function. For different vegetable categories, the function with the best fitting degree is adopted to establish the price-sales model. The final determined parameters are shown as table 1:

Table 1. Table of fitted model parameters

Name of category	Name of model	Parameters of the model
Aquatic rhizomes	Function of logarithm	[-26.110, 2.517, 83.605]
Mosaic leaf type	Function of logarithm	[-36.008, 2.354, 209.757]
Cauliflower type	Linear function of	[-2.892, 64.202]
Cauliflower type	Function of logarithm	[-8.162, 1.624, 36.470]
Chili pepper type	Function of logarithm	[-17.076, 3.108, 105.164]
Edible fungus	Linear function of	[-3.289, 92.537]

In order to obtain commodity profits, we also need to predict the average wholesale price of vegetable categories. The calculation formula of the average wholesale price of vegetable categories is as follows:

$$whole\_avg\_sale_{i,d} = \frac{\sum_{j\in i}(1 + attrition_i) *sale\_num_{j,d} *wholesale_{j,d}}{\sum_{j\in i}(1 + attrition_i) *sale\_num_{j,d}} \quad (3)$$

3. Autoregressive differential moving average ARIMA model

Autoregressive differential moving average model (ARIMA) is a commonly used statistical model in time series analysis, which is used to describe and predict the changing trend of time series data. Its main components are as follows:

Autoregressive: Consider the effect of the value at past time points in time series data on the current value

Integrated: A subtraction operation on time series data

Moving Average: Consider the effect of errors at past time points in time series data on the current value

ARIMA model parameters are represented by corresponding (p, d, q), corresponding to the order of autoregression, difference and moving average. For the establishment of ARIMA model, the optimal parameters need to be selected. Akaike Information Criterion, AIC, the optimal parameters selected are (2,2,2). In turn, the future average wholesale price is predicted.

4. Nonlinear programming model of total replenishment and pricing strategy for each vegetable category in the next week

After obtaining the average wholesale price of vegetable categories and the price-sales volume model, we construct a nonlinear programming model to solve for the optimal total replenishment and pricing policy. The constructed nonlinear programming model is as follows:

$$objetive{:}\ max(profit_{i,d} = sale_{i,d} * sale\_num_{i,d} - supply_{i,d} * wholesale_{i,d}) \tag{4}$$

The objective function is to maximize the benefit of the supermarket in vegetable category i on day d, which means total sales price - total wholesale price, $supply_{i,d}$ is the replenishment amount of commodity i on day d, and $sale_{i,d}$ is the sales volume of commodity i on day d.

$$s.t.\ supply_{i,d} > sale\_num_{i,d} + attrition_i * supply_{i,d} \tag{5}$$

The constraint function 1 is that the replenishment quantity is greater than the sales volume plus the loss quantity.

$$sale_{i,d} > wholesale_{i,d} \tag{6}$$

The constraint function 2 is that the selling price is greater than the cost wholesale price.

$$sale_{i,d}, supply_{i,d} > 0 \tag{7}$$

The constraint function 3 is that the replenishment quantity and sales pricing are greater than 0.

$$\mathrm{sale\_num}_{i,d} = \mathrm{func}(\mathrm{sale}_{i,d}) \tag{8}$$

Constraint function 4 is the price-sales function, through which the sales volume can be determined by the sales pricing, and the daily replenishment quantity and pricing strategy of vegetable categories in the next week can be obtained by substituting the data to solve the problem.The predicted results based on the data are shown in Table 2:

(Data from: www.mcm.edu.cn)

Table 2. Forecast results

date	category	Quantity of purchase	Fix a price	category	Quantity of purchase	Fix a price
1	Aquatic rhizomes	10.953	19.629	solanacea	17.073	14.006
2	Aquatic rhizomes	10.944	19.634	solanacea	17.081	13.700
3	Aquatic rhizomes	10.828	19.700	solanacea	17.065	14.018
4	Aquatic rhizomes	10.808	19.711	solanacea	17.070	14.011
5	Aquatic rhizomes	10.792	19.720	solanacea	17.066	14.016
6	Aquatic rhizomes	10.785	19.724	solanacea	17.064	14.019
7	Aquatic rhizomes	10.779	19.728	solanacea	17.063	14.021
1	anthophyllum	159.741	9.441	capsicum	76.957	11.019
2	anthophyllum	159.999	9.397	capsicum	76.788	11.091
3	anthophyllum	160.070	9.385	capsicum	76.967	11.015
4	anthophyllum	159.961	9.403	capsicum	76.814	11.080
5	anthophyllum	160.149	9.371	capsicum	76.988	11.007
6	anthophyllum	160.007	9.396	capsicum	76.838	11.070
7	anthophyllum	160.200	9.363	capsicum	77.009	10.99781234
1	cauliflower	22.078	15.752	Edible mushroom	54.249	13.201
2	cauliflower	22.100	15.745	Edible mushroom	52.537	13.672
3	cauliflower	22.086	15.749	Edible mushroom	51.983	13.825
4	cauliflower	22.100	15.745	Edible mushroom	53.426	13.427
5	cauliflower	22.089	15.748	Edible mushroom	51.832	13.866
6	cauliflower	22.100	15.745	Edible mushroom	53.390	13.438
7	cauliflower	22.092	15.748	Edible mushroom	52.055	13.805

5. Nonlinear programming model of the daily replenishment amount and pricing strategy of each vegetable single product in the next day

In the actual operation process of the supermarket, it is necessary to consider the minimum display quantity requirements of controlling the total number of saleable single products and the order quantity of single products when replenishment, so as to maximize the profit of the supermarket on the premise of meeting the market demand for various types of vegetable products as much as possible. The items that the supermarket can restock on a future day are similar to those sold in the previous week, and then the list of items that can be purchased is obtained.

Firstly, the wholesale price of each single product in the next day is predicted. Here, we use the historical average prediction method to obtain the future wholesale price $\mathrm{wholesale}_{j,d}$, and define the nonlinear programming model as follows:

objective: $max(profit_d = \mathrm{select_d} * \mathrm{sale_d} * \mathrm{sale\_num_d} - \mathrm{select_d} * \mathrm{supply_d} * \mathrm{wholesale_d})$ (9)

The objective function is to maximize the sales profit of the supermarket, which is the sum of the sales profit of each vegetable item. Here, we use a choice list $\mathrm{select_d}$ to control the purchase quantity of a vegetable item, which is a list of length 49 and the value is 0 or 1, with 0 indicating no purchase and 1 indicating purchase (constraint function 9).

$supply_d$ is the replenishment quantity list, the length is 49, and the value is the purchase quantity of a single vegetable product; $sale_d$ is the selling price list, the length is 49, and the value is the selling unit price of a single vegetable product.

$$s.t.: select_d * supply_{j,d} > select_d * sale\_num_{j,d} + select_d * attrition_i * supply_{j,d}, wh \tag{10}$$

Constraint function 1 is used to satisfy the requirement that the replenishment amount is greater than the sales volume plus the loss amount.

$$sale_{j,d} > wholesale_{j,d} \tag{11}$$

The constraint function 2 is used to satisfy the requirement that the selling price is greater than the wholesale price.

$$select_d * supply_{j,d} > select_d * 2.5 \tag{12}$$

The constraint function 2 is used to satisfy the requirement that the selling price is greater than the wholesale price.

$$27 \leq sum(select_d) \leq 33 \tag{13}$$

Constraint function 4 is used to meet the requirement of single item selection quantity.

$$select_d * supply_{j,d} = supply_{j,d} \tag{14}$$

The constraint function 5 is used to satisfy the requirement that the replenishment quantity list has the same zero element value position as the selection list.

$$select_d * sale_{j,d} = sale_{j,d} \tag{15}$$

The constraint function 6 is used to satisfy the requirement that the selling price list has the same zero element value position as the choice list.

$$sale\_num_{j,d} = func(sale_{j,d}), where\ j \in i \tag{16}$$

Constraint function 7 is based on the pricing and sales volume function of the vegetable category obtained in Question 4.2, and the sales volume of the vegetable single product is obtained through the category and pricing of the vegetable single product.

$$num(i) = 6 \tag{17}$$

Constraint function 8 is used to meet the market demand for various categories of vegetable commodities, and there are a total of six categories of vegetable single products requiring replenishment.

$$select_d = [random.randint(0, 1)\ for\ \_\ in\ range(49)] \tag{18}$$

Constraint function 9 defines purchase and no purchase, and solves the replenishment and pricing strategy of each vegetable single item in the supermarket in the next day. The results predicted by using the data are show in Table 3.

Table 3. Data prediction result

Name of item	Quantity of purchase	Price of sale
Colorful pepper (2)	28.367	18.987
Shanghai Green	3.542	8
Yunnan oilwheat vegetable (servings)	20.771	4.159
Yunnan Lettuce (serving)	14.165	4.462
Net lotus root (1)	0	0
Agaricus bisporus (box)	0	0
Round eggplant (2)	28.582	6.133
Chrysanthemum chrysanthemum	0	0
Milky cabbage	8.539	4.792
Ginger, Garlic, millet and pepper Combo (small)	20.986	4.722
Baby Chinese cabbage	5.602	6.541
crinkle (part)	0	0
Millet pepper (part)	14.095	5.769
Small Green Vegetables (1)	9.499	5.2
Black fungus	15.989	5.332
Branch Jiang green stalk scattered flowers	0	0
Honghu lotus root belt	0	0
Sea mushrooms (bun)	24.680	2.748
Bamboo leaf	12.496	3.774
Eggplant (2)	0	0
Red Pepper (2)	5.628	18.892
Red lotus root belt	0	0
Sweet potato tips	0	0
Wuhu Green Pepper (1)	7.729	5.2
amaranth	0	0
Flowering cabbage	0	0
Spinach	4.760	14
Spinach (portion)	4.223	5.510
Water caltrop	29.868	14
Cordyceps flower (part)	9.693	3.613
Screw pepper	16.075	11.291
Screw pepper (part)	0	0
Crab Mushroom and White Jade Mushroom Double combination (box)	0	0
broccoli	19.391	12.408
Xixia Mushroom (1)	22.806	24
Flammulina mushrooms (box)	19.100	1.880
Solanum japonicum	0	0
Green Red Hangzhou Pepper combination (part)	29.031	5.493
Green thread pepper (part)	22.701	4.3
Green Eggplant (1)	4.142	6
Tall Melon (1)	0	0
Yunnan romaine vegetable	25.668	7.2
Yunnan lettuce	14.288	9.2
Tall Melon (2)	0	0
White mushroom (bag)	0	0
Fresh fungus (part)	0	0
Chinese auriculae (serving)	0	0
Eggplant (1)	26.760	9
Wild pink lotus root	23.372	26

（Data from： www.mcm.edu.cn)

6. Conclusion

In this paper, combined with the data collected for the fruit and vegetable categories of commercial supermarkets, combined with the limiting factors in the actual operation process, the previous sales data are analyzed, and then the model is established to predict, and the total replying amount and pricing strategy of each vegetable category in the next week and each vegetable single product in the next day are obtained, so as to help the operators to make decisions.

In the process of model building, it is based on a large amount of realistic data such as sales data, commodity information and wholesale prices, so it has the potential to more accurately reflect the actual demand and changes in the market. Multiple factors are considered, including sales volume, cost, loss rate and wholesale price, etc., and the impact of these factors on sales profit is comprehensively analyzed to make the decision more comprehensive. The use of ARIMA models to predict future wholesale prices and to make optimization decisions based on nonlinear programming helps the supermarket to better plan replenishment and pricing strategies. The cost-plus pricing method is adopted to take into account the impact of transportation loss and quality decline on pricing, which helps to maintain a reasonable profit level. In the process of optimization, the model tries to meet the market demand for various types of vegetable commodities, which helps to increase the sales volume and maximize the profit of the supermarket.

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