Research on optimal pricing and replenishment strategy of vegetable commodities

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Abstract. The vegetables themselves have the characteristics of short fresh-keeping period, large price fluctuation and seasonal strength. Our country at present researches the industrial chain of vegetable commodities mainly from the production aspect to study the law of vegetable pricing for the production and income insurance that guarantee farmers' rights and interests or for the purchase buyer. And supermarket operators need to according to the historical sales data of each commodity, in the case of not knowing the specific single product and purchase price to make the replenishment and pricing decision of each vegetable category, so the research on the pricing and replenishment strategy of vegetable commodities has important practical significance. From the perspective of supermarket operators, based on ARIMA time series forecasting model and price elasticity model, this paper puts forward the optimal pricing strategy for vegetable commodities, and then establishes a single objective programming model to formulate replenishment strategy and optimize it with particle swarm optimization algorithm, so as to obtain the optimal replenishment strategy. The following conclusions are obtained: the optimal unit price is the price elasticity coefficient multiplied by the change of sales volume plus the unit price at the previous moment; The replenishment strategy should consider the influence of unit price on sales volume, and make multiple tradeoffs so as to maximize the profit of supermarket. It is of great significance for the operation and development of the enterprise to help the supermarket to maximize its profit and improve customers' satisfaction at the same time.

Keywords: Vegetable Commodities, Replenishment and Pricing Strategy, ARIMA Time Series Forecasting Model, Particle Swarm Optimization, Price Elasticity Model.

1. Introduction

Vegetable commodities occupy an important place in the economic life of our country. In recent years, with the consumers' pursuit of healthy diet and the development of diversified demand for vegetables, the vegetable market has brought new opportunities. At the same time, with the formation of large market and large circulation pattern, the price of vegetable commodities fluctuates frequently and violently in cross-regional and multi-level circulation, facing problems [1] difficult transportation and sales, and the vegetable market is also facing new challenges. Due to the long industrial chain of China's vegetable market, complex production and marketing links, market supply and demand relations and price fluctuations and other factors, to the production and consumption have brought a certain degree of uncertainty and risk. Therefore, the research and supervision of vegetable commodities in our country are also constantly strengthening.

At present, the domestic research on vegetable commodities is mainly from the perspective of production to protect the rights and interests of farmers put forward insurance [2] measures and planting suggestions, and [3] from the perspective of buyers to study the nutritional value of vegetables.[4] With the development of economy and the improvement of people's living standards, the market demand for vegetable commodities is increasing day by day, and the pricing and replenishment management of vegetable commodities are also put forward higher requirements.

Supermarket operators need to formulate reasonable pricing and replenishment strategies for each category of vegetables according to the historical sales volume, unit price and purchase price of each category of vegetables, so as to increase supermarket profits as much as possible and improve customer satisfaction.

From the perspective of supermarket operators, considering that vegetable commodities themselves have the characteristics of short shelf life, easy to spoil and strong seasonality, this paper needs to formulate reasonable replenishment and pricing strategies in advance. On the one hand, it is necessary to increase supermarket profits as much as possible, and on the other hand, it is of great practical significance to the operation and development of enterprises to provide customers with more satisfactory commodities. This paper uses mathematical models such as ARIMA time series prediction model and particle swarm optimization algorithm to quantitatively analyze the pricing and replenishment strategies of vegetable commodities. MATLAB and SPSS software are used as tools to improve operational efficiency and accuracy, and economic theories such as price elasticity model are used as theoretical basis to maximize the profits of supermarkets. It has important application value in vegetable commodity pricing and replenishment.

2. Theoretical basis of the model

2.1. ARIMA time series prediction model

ARIMA time series prediction model, also known as differential integrated moving average autoregressive model, is a common time series prediction model, mainly used to fit and predict time series data [5].

The structure of the ARIMA model can be expressed as s $ARIMA(p,d,q)$, where p,d and q represent the order of the autoregressive term, integral term and moving average term respectively. By choosing the appropriate p,d and q, an ARIMA model can be constructed that fits the specific time series data, allowing for efficient predictions. The formula is as follows:

$$(1-\sum_{i=1}^{p}\Phi_i L^i)(1-L)^d X_i = (1+\sum_{i=1}^{q}\theta_i L^i)\varepsilon_i, \tag{1}$$

Where p, represents the autoregressive order, d represents the difference order, q represents the moving average order, and ε_i represents the white noise sequence.

Firstly, according to the daily wholesale price, unit sales price and sales volume of vegetable items, the average daily sales volume, unit sales price and wholesale price of each vegetable item were calculated on a weekly basis from 2020-07-03. Then, vegetable items were classified according to the commodity information, and the average daily sales volume, unit sales price and wholesale price of each vegetable category were obtained. Then ARIMA time series forecasting model was used to predict the average daily wholesale price, average unit sales price and average sales volume of each vegetable category in the future.

2.2. Price elasticity model

In order to analyze the relationship between the sales volume and the unit price of each vegetable category, the price elasticity model is introduced from the economic principle and the price elasticity coefficient (PED) is introduced. The calculation formula is as follows:

$$PED_j = \frac{\Delta p_j}{\Delta s_j} = \frac{p_{tj} - p_{(t-1)j}}{s_{tj} - s_{(t-1)j}}, \tag{2}$$

Where $PED_j, p_j, s_j, p_{tj}, p_{(t-1)j}, s_{tj}, s_{(t-1)j}$ represents the j type of vegetables respectively Price elasticity coefficient, unit price of sales per day, total sales per day, unit price of sales at present moment, unit price of sales at previous moment, total sales at present moment, total sales at previous moment.

The price elasticity coefficient is calculated by MTALAB software, that is, the relationship between the total sales of each vegetable category and the unit sales price is obtained. The price elasticity coefficient represents the sensitivity [6] of sales volume to sales price. The larger PED is, the higher the sensitivity of sales volume to sales price.

Combining the price elasticity model and the ARIMA time series forecasting model, the pricing strategy is obtained, namely:

$$p_{(t+1)j} = PED_j \cdot (s_{(t+1)j} - s_{tj}) + p_{tj}, \tag{3}$$

2.3. Single objective programming model

Through the price elasticity model, the relationship between sales volume and sales unit price is obtained, and the sales volume is equal to the replenishment amount minus the loss amount, namely:

$$s_j = k_j(1-o_j), \tag{4}$$

Where, s_j, k_j, and o_j respectively represent the daily sales volume, replenishment volume and loss rate of category j vegetables.

Thus, the relationship between the quantity of replenishment and the unit price of sales can be obtained, and the profit can be further obtained:

$$z = \sum_{j=1}^{6}(p_j \cdot s_j - k_j \cdot l_j), \tag{5}$$

Where, z, p_j, s_j, k_j, l_j represents the daily profit of the supermarket, the unit price of sales, the sales volume, the replenishment quantity and the purchase price of Class j vegetables respectively.

The objective function should be the maximum profit of commodity surplus, and constraint conditions are established according to the two conditions that the replenishment quantity is 0.8-1.2 times of the demand and the replenishment quantity cannot be negative, and the single objective programming model is obtained:

$$\begin{aligned} &\max z = \sum_{j=1}^{6}(p_j \cdot s_j - k_j \cdot l_j) \\ &s.t. \begin{cases} 0.8s_j \le k_j \le 1.2s_j \\ k_j \ge 0 \quad ,1 \le j \le 6 \end{cases} , \end{aligned} \tag{6}$$

2.4. Particle swarm optimization

Particle swarm algorithms are mainly used to solve optimization problems and were proposed by Dr. Eberhart and Dr. Kennedy in 1995. It is an intelligent algorithm designed by simulating the predatory behavior [7] of flocks of birds. There are different food sources in the area, large and small, and the task of the flock is to find the largest food source, the local optimal solution. In the whole search process, the birds pass on their location information to each other, so that other birds know the

location of the food source, and finally the whole flock can gather around the food source, which is what we say to find the optimal solution [8].

The flow of particle swarm optimization algorithm is shown in Figure 1:

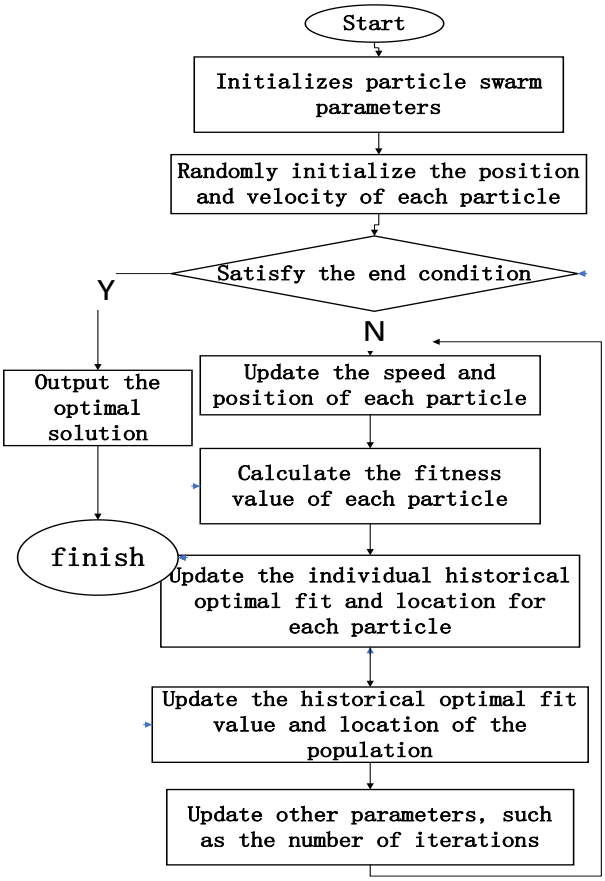

Figure 1. Flow chart of particle swarm optimization algorithm

Firstly, the initial parameters are defined, and the position and speed of each particle of the particle swarm are randomly initialized, and the fitness value [9] p_{best} and the global optimal value g_{best} are recorded. Then, the speed and position of each particle are updated iteratively. In each iteration, the fitness value of each particle is calculated and compared with p_{best}. If it is better, it is used as the latest g_{best} until the preset maximum number of iterations is reached, and the optimal solution is output.

The particle swarm optimization algorithm was used to optimize the daily replenishment amount of each vegetable category from July 1-7, 2023, and seek the optimal replenishment amount to maximize the profit.

3. Results

3.1. Data Sources

The data is obtained from: http://www.mcm.edu.cn/.

3.2. Result Analysis

(1) Stationarity test and stationarity treatment:

SPSS software was used to test the stationarity of the time series of the daily sales volume, unit price and purchase price of each vegetable category by using ADF unit root test method, and the data were stabilized by difference method. The results are shown in Table 1:

Table 1. ADF test results

	Difference order	ADF value	P value	Conclusion
Sales Volume	0	-2.355	0.155	Unstable
	1	-4.525	0.01	Stable
Unit price of sales	0	-2.564	0.101	Unstable
	1	-11.157	0.004	Stable
Purchase price	0	-2.943	0.041	Stable

It can be seen from Table 1 that the P-values of the time series of the sales volume and unit price of each vegetable category are 0.155 and 0.101 respectively, which are non-stationary series. SPSS software is used to make first-order difference respectively, and the P-values of the time series after difference are 0.01 and 0.004 respectively by ADF test. Therefore, the sequence of sales volume and unit price of each vegetable category after first-order difference is a stationary series [10], which reflects that this data is initially applicable to ARIMA after first-order difference, and the D-value is 1. The P-value of the time series of the purchase price of each vegetable category is 0.041, which is a stationary series, and this data is initially applicable to ARIMA, and the d value is 0.

(2) Model ordering:

After the data was stabilized, the ARIMA model was fitted. MATLAB software was used to make autocorrelation graphs and partial autocorrelation graphs of the sales volume, unit price and purchase price of each vegetable category respectively, and the optimal model order p and q [11]. The results are shown in Figure 2:

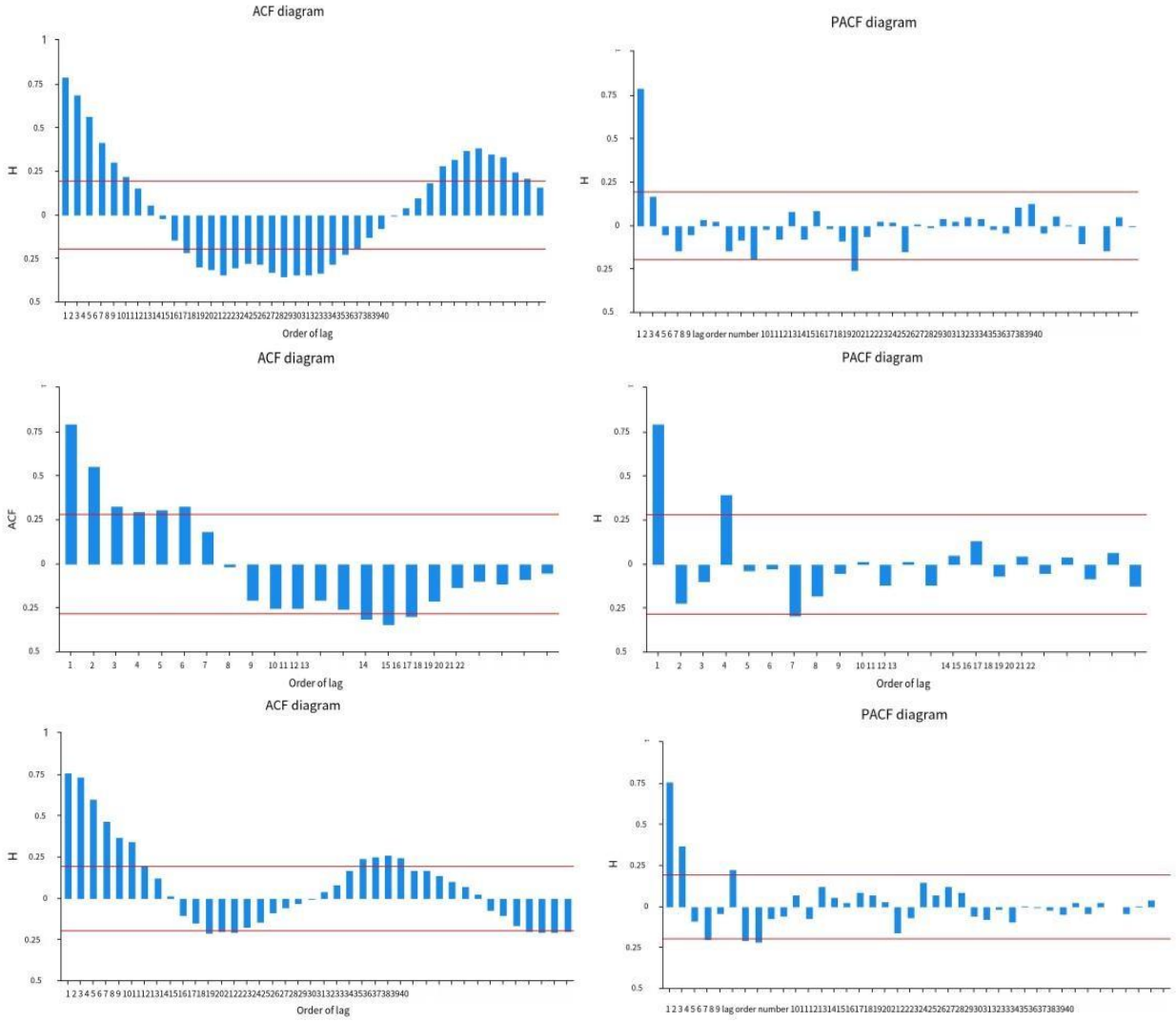

Figure 2. ACF diagram and PACF diagram

According to the sales volume, unit price and purchase price of each category of vegetables, combined with the ACF and PACF charts, it is found that ACF and PACF all show a tail, and basically fall within the 2 standard deviation range at the first order position, so $p = 1$ and $q = 1$ are selected. Therefore, model $ARIMA(1,1,1)$, model $ARIMA(1,1,1)$ and model $ARIMA(0,1,1)$ are selected for the sales volume, unit price and purchase price of each category of vegetables respectively.

(3) Residual white noise test:

Ljung-Box test [12] was used to conduct white noise test on the residual sequence of the determined best model. The results are shown in Table 2. It can be seen that the Q statistics of the sales volume, unit price and purchase price of each vegetable category are 1.44, 2.06 and 2.26 respectively, and the P-values are 0.24, 0.32 and 0.52, all of which are greater than 0.05. The results show that there is no correlation between the residual sequences and they belong to white noise sequences, which can be predicted by this model.

Table 2. Ljung-Box test results

	Model	Q Statistics	P value
Sales volume	ARIMA (1,1,1)	1.444106	0.242
Unit price of sales	ARIMA (1,1,1)	2.063523	0.316
Bid	ARIMA (0,1,1)	2.26302	0.519

(4) Prediction:

The ARIMA time series forecasting model was used to predict the future average weekly wholesale price, unit selling price and sales volume of each vegetable category. Table 3 shows the average weekly wholesale price, unit selling price and sales volume of Mosaic vegetables in the next 5 weeks.

Table 3. Sales data of Mosaic vegetables in the next 5 weeks

Date	1 week Later	2 weeks Later	3 weeks Later	4 weeks Later	5 weeks Later
Average sales	17.424	17.785	18.074	18.356	18.609
Average unit sales	8.694	9.864	9.865	10.64	11.99
Average bid	3.85	4.262	4.627	4.841	4.967

(5) Pricing strategy:

MATLAB software is used to calculate the price elasticity coefficient of each vegetable category according to the predicted value of the sales volume and the unit price of each vegetable category, and the results are shown in Table 4. According to Table 4, the price elasticity coefficients are all negative, indicating that there is a negative correlation between sales volume and unit price. The sales volume of aquatic rhizomes, nightshade and edible fungi is more sensitive to price changes, that is, the sales volume may be more sensitive to the increase of selling price. The sensitivity of the sales volume of Mosaic, chili and cauliflower to the price change is relatively low, that is, the increase of selling price may have little impact on the sales volume.

The optimal pricing strategy can be obtained from the price elasticity formula: the selling price is equal to the price elasticity coefficient multiplied by the change in sales volume plus the selling price at the previous moment, so the selling price of each vegetable category can be obtained as shown in Table 4.

(6) Replenishment strategy:

The maximum profit of each vegetable category in the coming week (July 1-7, 2023) is 2,413.34 yuan based on the single objective programming model established by MATLAB software, and the optimal daily replenishment amount is shown in Table 4.

Table 4. Price elasticity coefficient, selling price and optimal replenishment amount

	Aquatic rhizomes	Mosaic vegetables	cauliflower	Nightshade	capsicums	Edible fungi
PED	-1.027	-0.583	-0.299	-0.740	-0.494	-0.586
Sale price	12.76	6.192	10.846	7.132	6.2427	3.712
Replenishment volume	7.77	64.738	13.038	8.714	44.1672	22.684

MATLAB software is used to optimize the total daily replenishment strategy with the help of particle swarm optimization algorithm to maximize the profit of supermarket. The iterative curve of particle swarm optimization algorithm is as follows:

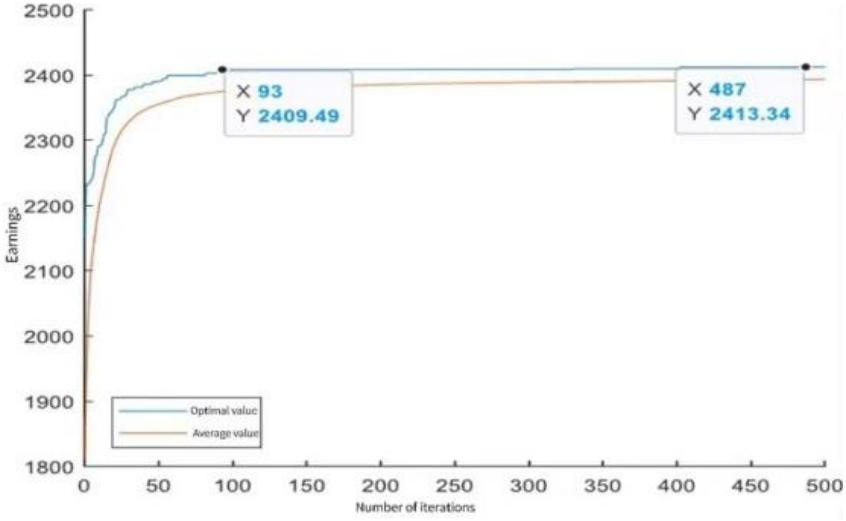

Figure 3. Iteration curve of particle swarm optimization algorithm

It can be seen from Figure 3 that the particle swarm optimization algorithm tends to converge after about 93 iterations, and the convergence speed is fast, indicating that the optimal solution can be found quickly. At the same time, the optimal value curve and the average value curve rise at the same speed, indicating that the algorithm can find a relatively good solution for each individual in the population, and the optimal replenishment quantity is obtained.

4. Conclusion

As vegetable commodities themselves have the characteristics of short shelf life, easy deterioration and strong seasonality, reasonable development of vegetable commodity pricing and replenishment strategy is of great significance for the operation and development of enterprises, which can not only improve the sales profit of enterprises, but also improve customer satisfaction and enhance their own competitive advantage. In this paper, a forecasting model based on ARIMA time series is proposed, and the price elasticity model and particle swarm optimization algorithm are used to rationally formulate the pricing and replenishment strategy of vegetable commodities. The following conclusions are obtained: the optimal unit price is equal to the price elasticity coefficient multiplied by the change of sales volume plus the unit price at the previous moment; The replenishment strategy of each vegetable category should consider the impact of the unit price on the sales volume, and weigh it in many ways so as to maximize the profit of the supermarket. In the planning, it is also necessary to consider the influence of various factors in accordance with the actual situation.

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