Replenishment and Pricing Strategies for Vegetable Commodities Based on Time Series

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Abstract. Due to the short freshness period of vegetables, to ensure the freshness of vegetables, commodities should be stocked in superstores to facilitate replenishment pricing. so a reasonable replenishment strategy is crucial to more effectively help superstores around the world to manage inventory, improve sales efficiency, optimize business management and maximize revenue. Based on this, this paper determines the future replenishment as well as pricing strategies of the commodities using the pricing, wastage, and replenishment of vegetables in a superstore for the last three years Goods Sample This data is based on a time series study. Wavelet analysis was used to study the cyclical regularity relationship, and based on this relationship, the trend relationship between the total sales volume of each vegetable category and the cost-plus pricing was analyzed, and the time-series model was used to predict the total daily replenishment volume of each vegetable category in the coming week, as well as the pricing of a single item, and TOPSIS-entropy weighting was used to assign the weights, and the predicted pricing of a single item was added to the price of a single item. The results achieve short-term price forecasting of vegetable commodities in the presence of low-price volatility, thus maximizing the superstore revenue.

Keywords: Small Wave Analysis, Time Series Forecasting, TOPSIS-Entropy Weighting Method.

1. Introduction

In fresh food supermarkets, the freshness period of vegetable commodities is relatively short, and the quality will deteriorate over time, so the supermarkets need to replenish the stock every different origins, supermarkets need to purchase goods in the early hours of the morning, and need to make replenishment decisions without knowing the specific single product and purchase price of the day, supermarkets usually use the cost-plus pricing method. Therefore, market demand analysis is crucial for supermarkets to make replenishment and pricing decisions.

In the vegetable replenishment forecasting problem, Chen Junxiao, et al. [1] utilized a pricing strategy and a replenishment strategy based on a cost-plus pricing approach, and then future sales of each category and single product were predicted based on the random forest algorithm, Ye Wenbo, et al. [2] used XG-Boost algorithm to establish a model with the maximum revenue of the supermarket in the coming week as the objective function, and the corresponding replenishment quantity and pricing strategy were obtained by genetic algorithm. Ping Haoyang, et al. [3] analyzed by K-means++ clustering, non-normal distribution evaluation, Spearman's correlation coefficient ,and heatmap, and finally autoregressive integral sliding average (ARIMA) model and long-short-term memory (LSTM) model were used to predict sales and determine the optimal replenishment quantity. The theory of price elasticity and an integrated model are used to predict changes in net profit, aiming to increase profitability by 47%. Tian ye, et al. [4] utilized theoretical frameworks such as K-Means cluster analysis and simple exponential smoothing models. Use time series model to predict the sales volume and pricing for the next 7 days, and then combine the cost-plus pricing and the effect of cost factors to formulate the optimal pricing and replenishment decision of supermarkets. [5] However, the current research shows that accurately forecasting vegetable prices remains difficult, vegetable price fluctuations, to control vegetable price fluctuations, this paper proposes a method based on time series with TOPSIS-entropy weighting method and normalization to a small degree of weighting.

This paper introduces an enhanced approach to normalized weighting that seeks to ensure vegetable prices are adjusted based on price weight while minimizing impact on people's daily lives.

The goal is to maximize superstore revenue by scientifically analyzing the economic principles governing common superstores and the pricing replenishment process, ultimately providing valuable insights for their operation.

2. Method

2.1. Overview of the methodology

In this paper, the problem of maximizing operating returns is solved using wavelet analysis, cost-plus pricing, time series, and TOPSIS-entropy weighting.

Firstly, wavelet analysis was used to study the cyclical pattern of sales volume of vegetable categories, and the trend relationship between the total sales volume of each vegetable category and the cost-plus pricing was analyzed to analyze the correlation between each category. Then, using the sales data of vegetable categories in the last two months, a time series model was used to predict the total daily replenishment volume of each vegetable category in the coming week as well as the pricing of individual items after the KPSS test. Finally, to maximize the revenue, the TOPSIS-entropy weighting method is used to assign the total sales volume and profit of individual items as the indicators, and finally, the normalization principle is used to add the predicted pricing multiplier of individual items.

2.2. Vegetable replenishment and pricing strategy prediction model constructed

Cost-plus pricing methodology was used, taking into account competition in the marketplace [6] the cost-plus pricing method is used to maintain price competitiveness to a certain extent. So the cost-plus pricing method is used as the basic mathematical model structure of this paper.

Solve for profit based on the following formula:

$$Q_{i,j,t} = m_{i,j,t} n_{i,j,t} - \frac{c_{i,j,t} n_{i,j,t}}{1-\varphi_{i,j,t}} \tag{1}$$

Where $Q_{i,j,t}$ is the profit earned by the superstore from the sale of j items in the i category on the day t, $m_{i,j,t}$ is the sales price of j items in the i category on day t, $n_{i,j,t}$ is the sales volume of j items in the i category on the day t, $c_{i,j,t}$ is the wholesale price of j items in the i category on the day t, and $\varphi_{i,j,t}$ is the wastage rate of j items in the i category on the day t.

Solve for the total number of sales per day according to the following formula.

$$A_{i,t} = \sum n_{i,j,t} \tag{2}$$

Where $A_{i,t}$ is the total sales volume of the category on day of t and $n_{i,j,t}$ is the sales volume of the j item in the category on the day t.

Cost-plus pricing is a pricing method that sets the price of a product by adding a percentage of the target profit to the unit cost.

$$L_{i,j,t} = \left(\frac{1+(m_{i,j,t}-c_{i,j,t})}{c_{i,j,t}}\right)(c_{i,j,t}+\varphi_{i,j,t}) \tag{3}$$

Where $L_{i,j,t}$ is the cost-plus pricing of j individual items in the i category on day t.

Further to analyze the correlation relationship between the categories of goods, so this paper uses the partial correlation coefficient method Pearson's correlation coefficient is expressed by measuring the ratio of the covariance of two variables to the product of their standard deviations.

Its linear correlation is calculated as follows:

$$r=\frac{\sum(X_i-\overline{X})(Y_i-\overline{Y})}{\sqrt{\sum(X_i-\overline{X})^2\sum(Y_i-\overline{Y})^2}} \tag{4}$$

Where X_i and Y_i are the i observations of the variables X and Y . The values of and are the mean values of the variables and. $\overline{X}$ and $\overline{\mathrm{Y}}$ are the mean values of the variables X and Y . Through these steps, the Pearson's correlation coefficient can be clearly calculated and the Pearson correlation coefficient can be utilized to measure the correlation between the total amount of replenishment and the price of different vegetable categories, which lays the foundation for the construction of a more accurate prediction model. Because of the seasonality of vegetable production, wavelet coefficients are used to analyze its periodicity. The function is expressed as a linear combination of a set of wavelet basis functions which are localized in the time domain and have a limited bandwidth in the frequency domain. By changing the size and shape of the basic functions, a multi-scale decomposition of the signal is realized, which can capture features at different scales. To further explore the time-frequency relationship involved, we introduce wavelet analysis [7-9] which deeply analyzes the distribution of sales volume laws.

$$\mathrm{A}_1(\mathrm{n})=\sum_k f(k)*h(k-n) \tag{5}$$

$$D_1(n)=\sum_k f(k)*g(k-n) \tag{6}$$

Where: $A_1(n)$ is the low frequency (near) factor? $D_1(n)$ Are the high-frequency (detail) coefficients $h(k)$ and $g(k)$ are the low-pass and high-pass filters of the wavelet analysis filter coefficients respectively.

After analyzing and obtaining the vegetable sales law, based on this law to forecast vegetable replenishment and pricing strategy, this paper uses a time series model.

For the analysis of the relationship between total sales and cost-plus pricing for each category, future daily replenishment totals and pricing strategies are to be given. Regression analysis is established to explore the relationship. The replenishment total and pricing strategy for the coming week are predicted separately using time series [10-14]. The observed values of each variable in the data file are arranged into a numerical sequence in chronological order, importing their change process over two month and analyzing their change characteristics, development trends, and patterns.

Autoregressive model AR:

$$y_t=\mu+\sum_{i=1}^{p}\gamma_i y_{t-1}+\varepsilon_t \tag{7}$$

Moving Average Model MA:

$$y_t=\mu+\varepsilon_t+\sum_{i=1}^{q}\theta_i\varepsilon_{t-i} \tag{8}$$

The differential autoregressive model ARIMA is expressed mathematically as:

$$y_t=\mu+\sum_{i=1}^{p}\gamma_i y_{t-i}+\varepsilon_t+\sum_{i=1}^{q}\theta_i\varepsilon_{t-i} \tag{9}$$

Autocorrelation function ACF

$$ACF(k)=p_k=\frac{Cov(y_t,y_{t-k})}{\mathrm{Var}(\mathrm{y}_t)} \tag{10}$$

Where p denotes predicts using two months of historical data, y_t is the current value, μ is the constant term, p is the order, γ_i is the autocorrelation coefficient, and ε is the perturbation term. γ_i Denotes the coefficient of AR and θ_i denotes the coefficient of MA.

3. Experiments and Results

3.1. Introduction to the data set

The data were obtained from https://github.com/eaaarqarar/data/tree/main/data (Chinese). Sample 1 contains data on the individual items included in each vegetable category, while Sample 2 contains data on the sales volume and sales price of each item from July 1, 2020, to June 30, 2023, the Sample 3 contains outliers for unsold.

3.2. Data Processing and Preprocessing

Sample 1 contains the data of the single product contained in each vegetable category, while sample 2 contains the data of the sales volume and sales price of every single product from July 1, 2020, to June 30, 2023, due to a large amount of data, to facilitate the subsequent solution of the problem, the use of excel pivot table method to deep-dive into the data processing, and did not find any missing values, the valid number of data in sample 1 will be Merge. The counts and numerical groupings for the six categories are shown in Table 1.

Table 1. Information on vegetable items included in the six vegetable categories.

Vegetable categories	Number of single items	Category number
Mosaic and leafy	100	1
Cauliflower	5	2
Aquatic rhizomes	19	3
Nightshades	10	4
Chili peppers	45	5
Edible mushrooms	72	6

In conjunction with the Sample 2 control, Sample 3 contained unsold outliers, which were eliminated. This is shown in Table 2.

Table 2. Exception information for sales.

Item number	The name of the item	Unit price of a single item
102900005116042	lotus root	15.32
102900005116776	Local spinach	10.46
102900011011782	Cordyceps Flower(Box)(1)	11.93
102900011023648	Wuhu Green Pepper(2)	8.78
102900011032145	Wuhu green pepper (portion)	9.43

3.3. Analysis of results

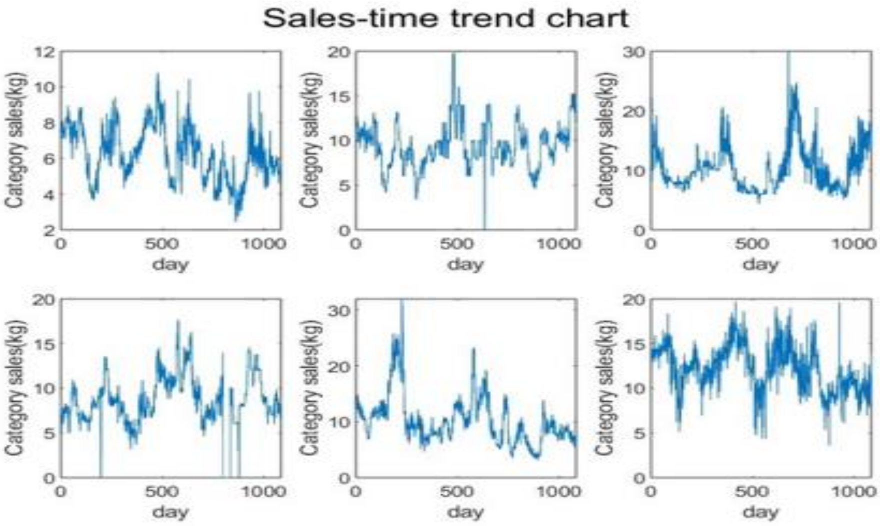

Figure 1. Sales-time trend chart.

Fig. 1 is the sales volume-time trend chart of the six categories of vegetables in the data set in the last three years, which can be seen that the daily sales cycle of the six types of vegetables changes in three years, six categories of sales in a certain period time each year there will be a sales volume is different from the peak value of other periods, and six categories of sales peak time are closer, presumably the Spring Festival or a grand festival.

The results of wavelet analysis are shown in Fig.2 the results show that after noise reduction, the wavelet coefficients show good periodicity.

The relationship between total sales and cost-plus pricing for each category was calculated as follows Fig.3.

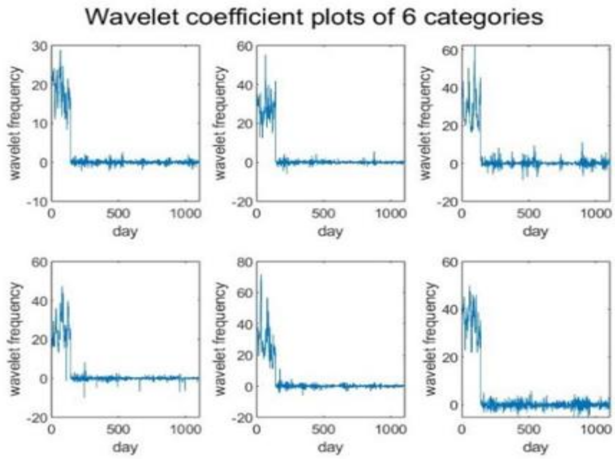

Figure 2. Wavelet coefficient plots of 6 categories.

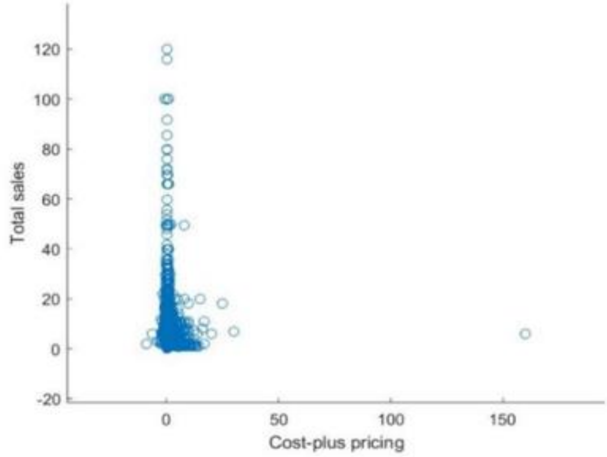

Figure 3. Total sales and cost-plus pricing.

For the analysis of total sales and cost-plus pricing, it can be seen that the smaller the cost-plus pricing, the larger the total sales. Total sales are negatively related to cost-plus pricing.

The forecast results, i.e., the replenishment strategy for the coming week, are shown in Table 3.

Table 3. Replenishment strategy for the coming week (unit: kg).

	Mosaic and leafy	Cauliflower	Aquatic rhizomes	Nightshades	Chili peppers	Edible mushrooms
Replenishment Quantity (kg)	148.1644	25.34322	15.74991	27.70213	88.43063	55.36745
	161.8023	23.67553	15.42627	25.09913	90.86746	63.60284
	162.3631	22.9674	15.37972	25.1297	89.8617	63.46115
	162.3861	22.66671	15.37302	25.12935	90.27681	63.46359
	162.3871	22.53904	15.37206	25.12935	90.10548	63.46355
	162.3871	22.48483	15.37192	25.12935	90.17619	63.46355
	162.3871	22.46181	15.3719	25.12935	90.14701	63.46355

After predicting the total replenishment and pricing strategy for each category of vegetables for the coming week using time series analysis using category sales total sales and profit as indicators, weights and scores were calculated using the TOPSIS-entropy weighting method. The total sales volume and profit of each item were used as indicators to assign weights, and finally, the score was calculated using the normalization principle to add a 1-1.2 multiplier to the predicted pricing of each item.

The results are shown in Table 4.

Table 4. Pricing table of final single product (unit: RMB/kg).

	Colorful peppers	broccoli	…	Small wrinkles	Bamboo leafy vegetables
July 1	0	21.6327	…	0	0
July 2	0	21.6397	…	0	0
July 3	0	21.6403	…	0	0
…	…	…	…	…	…
July 7	0	21.6427	…	0	0

Through the analysis, 6 kinds of vegetables between categories and 251 kinds of vegetables between individual products may have a certain correlation, to the category as a unit to develop a replenishment plan, analyze the total sales of each vegetable category and the relationship between the cost-plus pricing; to develop each vegetable category in the next week, that is, the total amount of daily replenishment and pricing strategy, so that the superstore to maximize the revenue.

We use wavelet analysis to explore the cyclical pattern of sales volume of vegetable categories, and the results show that each vegetable category has a strong cyclical pattern; we plot the wavelet coefficient graph and carry out the partial correlation test, and the results show that there is a strong correlation between each vegetable category. Finally, for the vegetable single product, the study found that the vegetable single product has a strong cyclical pattern, and the number of overall upward trend. Plotting and analyzing the trend relationship between total sales volume and cost-plus pricing for each vegetable category, the results show that total sales volume is negatively correlated with cost-plus pricing. Secondly, using the sales data of vegetable categories in the past two months, a time series model is used to forecast the total replenishment volume and the pricing of individual items for each vegetable category in the coming week after passing the KPSS smoothness test.

The established time series model forecasts the daily replenishment for six categories: Foliage, Cauliflower, Aquatic Roots, Solanaceae, Chili Peppers, and Edible Mushrooms. The predicted amounts for the next day are 162.38 kg for Foliage, 22.46 kg for Cauliflower, 15.37 kg for Aquatic Roots, 25.12 kg for Solanaceae, 90.14 kg for Chili Peppers, and 63.46 kg for Edible Mushrooms. The mean squared error of the predicted data does not exceed 2.5 and the model performs well. Finally, to maximize the superstore's revenue, the TOPSIS-entropy weighting method is used to assign weights to the total sales volume and the profit of a single product as indicators, and the final scores are added to the predicted pricing of a single product at a 1-1.2 multiplier, Taking bamboo leafy vegetables as an example, the pricing strategies for each day of the coming week are as follows: 13.63 (RMB/kg), 8.44 (RMB/kg), 11.04 (RMB/kg), 9.71 (RMB/kg), 10.37 (RMB/kg), 10.01 (RMB/kg), 10.17 (RMB/kg).

Through in-depth analysis of vegetable sales data, it can help superstores better understand the correlation between different vegetable categories and individual products, to formulate more effective replenishment plans and pricing strategies to maximize superstores' revenue. At the same time, analyzing the relationship between total sales volume and cost-plus pricing can help superstores rationalize pricing to ensure that sales can cover costs and make profits.

Developing replenishment totals and pricing strategies for the coming week will allow you to adjust the replenishment and pricing of each vegetable category based on historical sales data and trend forecasts, combined with current market demand and competition, to achieve the goal of maximizing superstore revenues.

4. Conclusion

Since a reasonable vegetable replenishment strategy can help maximize superstore revenues, this paper utilizes wavelet analysis to study cyclical patterns and analyze the trend relationship between total sales and cost-plus pricing for each vegetable category. A time series model was used to predict the total daily replenishment of each vegetable category in the coming week and the pricing of individual items. The TOPSIS-entropy weighting method was used for the assignment of weights, and the predicted individual item pricing was ultimately weighted with the corresponding multiplier to maximize profit under stable supply and demand, with the mean square deviation is less than 2.5.

The result establishes a short-term price prediction model for vegetable commodities in the case of low-price volatility, to maximize the revenue. It provides a reference method and idea for the superstore class enterprises, and provides a theoretical basis and research idea that can be referred to for superstore replenishment pricing. In the future, we will focus on new algorithm models and supply chain optimization. We will explore more advanced algorithms to improve the accuracy of vegetable price and replenishment quantity forecasts. At the same time, we will study the efficiency of each link in the vegetable supply chain to optimize inventory management and transportation processes, thereby reducing costs. We aim to achieve more efficient supermarket operations and provide strong support for market competition

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