# Pricing and replenishment strategy formulation for the fresh produce market

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**Abstract.** To improve the profit margin of the fresh supermarket and optimize the pricing and replenishment strategies of goods, this article provides a time series analysis of the sales volume of various categories and individual items of vegetables. The sales volume and the relationship with time are analyzed on a monthly, quarterly, and annual basis. The article discovers the seasonal and cyclical patterns in the sales volume of vegetable categories and individual items. Using the Spearman correlation coefficient and hypothesis testing, the study reveals strong positive correlations in the sales volume of cauliflower and leafy flower products, as well as strong negative correlations in the sales volume of eggplant and aquatic root and stem products. To formulate pricing strategies for the fresh supermarket in the coming week, the article uses the ARIMA model to forecast the daily total sales volume of various categories. It also constructs a planning model for maximizing the revenue of the fresh supermarket, taking expected profit margin, discount factors, and daily replenishment total as independent variables. The simulated annealing algorithm is employed to solve this model, and the result indicates that the maximum revenue for the fresh supermarket in the coming week is 4269.6 yuan. The article provides procurement and pricing strategies for the fresh supermarket in the next week based on this analysis.

**Keywords:** Planning Model, Simulated Annealing Algorithm, TOPSIS, ARIMA.

## 1. Introduction

In recent years, with the development of social economy, people's demand for fresh products has increased dramatically. The supply chain of fresh products represented by fruits and vegetables is also developing rapidly. The inventory and distribution problems of vegetable commodities have received extensive attention. The most significant characteristic of vegetable commodities is their perishability, even if they are stored properly, they will deteriorate, and the resulting inventory loss and waste are very serious. Whether it is inaccurate inventory due to quantity decay or expired product abandonment due to quality decay, it will bring losses to retailers and cause revenue decline. Therefore, it is of great practical significance to study the ordering and pricing strategy of vegetable inventory model.

For the perishable characteristics of fresh produce, Nahmias (1982)[1]provides a comprehensive summary of similar studies prior to the 1980s, and a related review of such studies is Goyal and Giri (2001)[2].Bi[3] et al. designed a joint inventory control and dynamic pricing algorithm for fresh produce based on deep reinforcement learning.Hongyao Zhang[4] et al. proposed a combined prediction model based on the gray GM(1,1) model and BP neural network for predicting the logistics demand of fresh products. Junxia Wang[5], on the other hand, studied the replenishment decision of dairy products.

However, for the pricing and replenishment strategy of vegetable commodities, there are fewer studies in the academic world. Therefore, this paper takes vegetable commodities as the research object, through analyzing the distribution law and correlation relationship of different categories and single product sales volume, based on the planning model combined with simulated annealing algorithm to develop the pricing and replenishment strategy to maximize the revenue.

## 2. Exploration and analysis of sales data for vegetable products

The data for this article is sourced from [http://www.mcm.edu.cn/html_cn/node/c74d72127066f510a5723a94b5323a26.html]. The dataset includes information on products from six categories of vegetables, detailed sales transaction data, wholesale prices for vegetable products, and recent loss rates for vegetable products.

### 2.1. Time series charts of sales volume for various categories of vegetable products.

The quarterly sales volume for each category is shown in Figure 1.

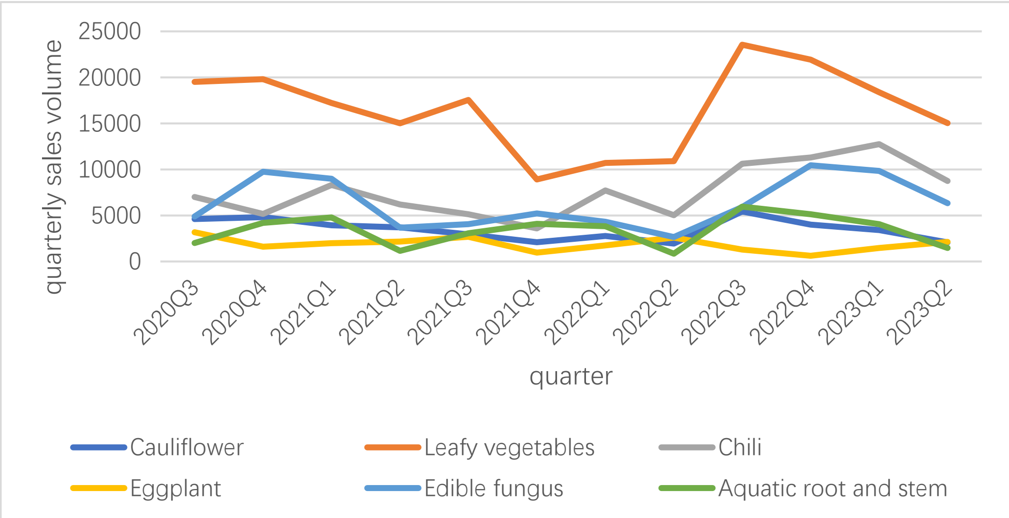
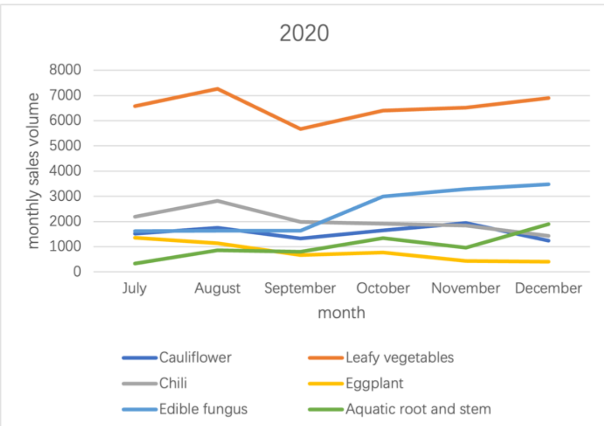


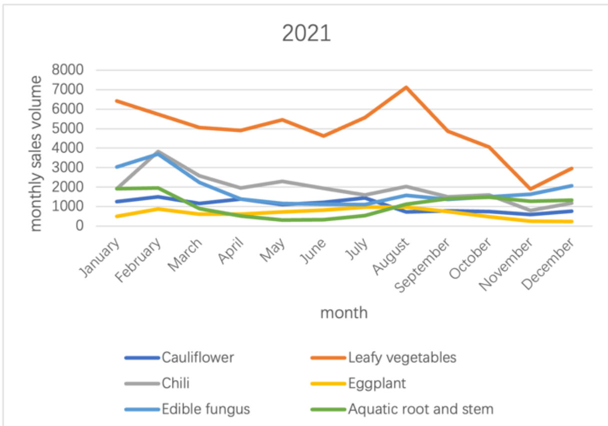

**Figure 1.** Quarterly sales volume for various categories

From Figure 1, it can be observed that the sales revenue of various categories shows a certain level of periodicity in each quarter. For example, floral and leafy vegetables, as well as cauliflower, are expected to experience a significant increase in sales revenue in the third and fourth quarters. On the contrary, eggplants, for instance, are anticipated to have a slight decrease in sales revenue in the third and fourth quarters each year. This suggests that there may be a negative or positive correlation among categories.

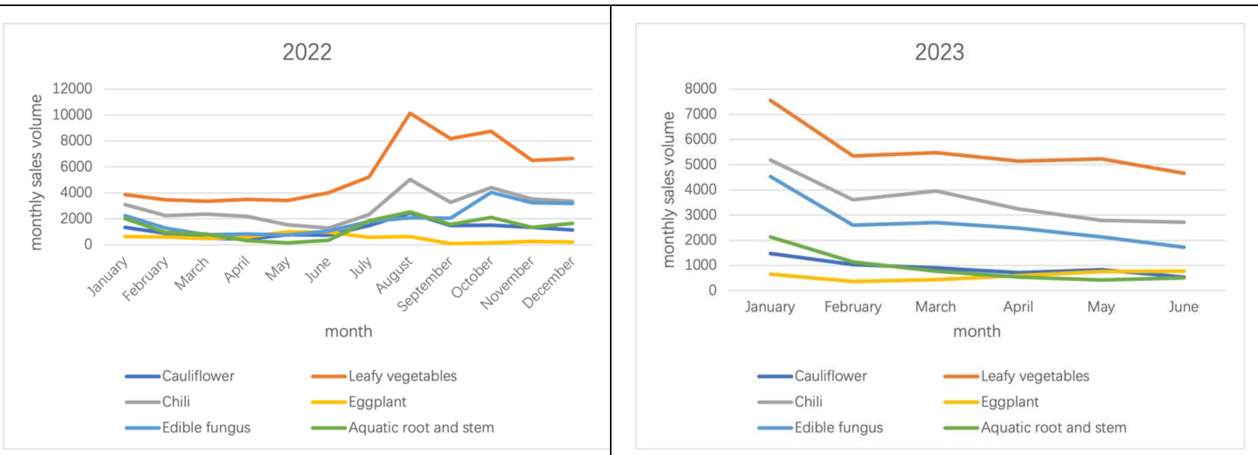
The monthly sales revenue is shown in Figure 2.




(a)




(b)




(c) (d)

**Figure 2.** Time series charts of monthly sales revenue for various categories

From Figure 2, it can be observed that the sales revenue of floral and leafy vegetables has consistently been the highest among all categories. Moreover, the data from 2021 and 2022 indicate a noticeable periodicity in the monthly sales revenue of floral and leafy vegetables.

### 2.2. Time series charts of sales volume for various categories of vegetable products

Using each product category as an indicator, the total sales volume for each category in each month is taken as a sample value. The sales volumes of each category for the 36 months are taken as samples. A matrix scatter plot is drawn to facilitate the assessment of the correlation between different product categories. The matrix scatter plot is shown in Figure 3:

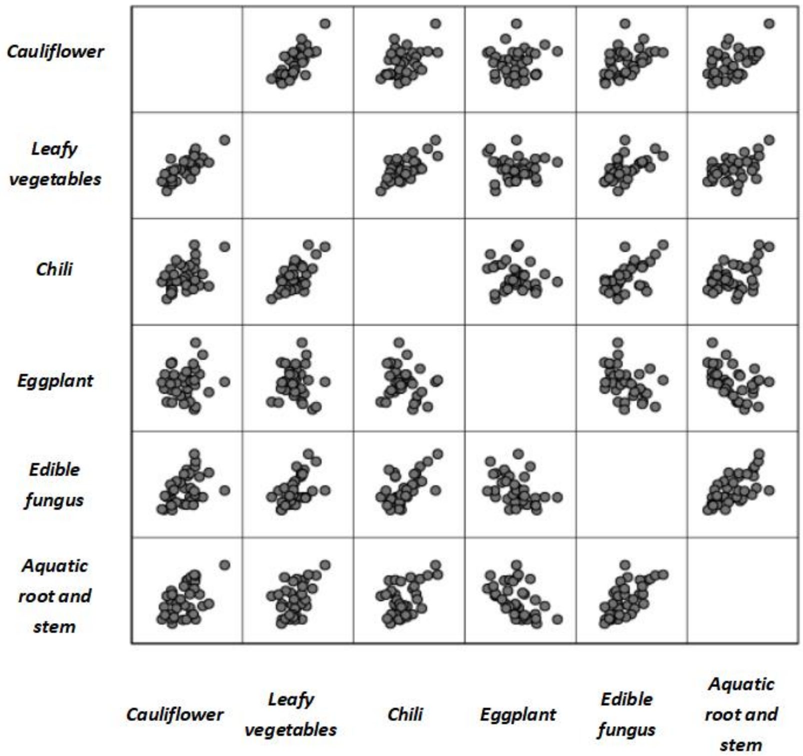



**Figure 3.** Matrix Scatter Plot

The Spearman correlation coefficients[6] for each product category were calculated, and corresponding p-values[7] were tested at a confidence level of 0.01. This analysis was conducted to assess the correlations between different product categories.

The Correlation coefficients and p-value is shown in Figure 4.

| | Cauliflower | Leafy vegetables | Chili | Eggplant | Edible fungus | Aquatic root and stem |
|---|---|---|---|---|---|---|
| Cauliflower | 1.00000 | .695** | 0.31017 | 0.07619 | .462** | .427** |
| Leafy vegetables | .695** | 1.00000 | .488** | -0.04324 | .578** | .448** |
| Chili | 0.31017 | .488** | 1.00000 | -0.16963 | .490** | 0.31634 |
| Eggplant | 0.07619 | -0.04324 | -0.16963 | 1.00000 | -.447** | -.467** |
| Edible fungus | .462** | .578** | .490** | -.447** | 1.00000 | .669** |
| Aquatic root and stem | .427** | .448** | 0.31634 | -.467** | .669** | 1.00000 |

**Figure 4.** Correlation Coefficients and p-Value Test Plot

The blue section indicates that there is no significant correlation between the corresponding product categories at a 99% confidence level. The white section represents a significant correlation between the corresponding product categories at a 99% confidence level, with the numerical values indicating the strength of the correlation. Values closer to 1 indicate a stronger positive correlation, while values closer to -1 indicate a stronger negative correlation.

## 3. The formulation of pricing and replenishment strategies for vegetable products

### 3.1. The Cost-Plus Pricing Method

The Cost-Plus Pricing Method[8] is a strategy for determining the selling price of goods, primarily applied in manufacturing and service industries. Its purpose is to ensure that a business can cover all costs associated with production or service provision and achieve a certain level of profit. The pricing method involves the following steps:

**Calculate Costs:** Initially, the business needs to calculate various costs associated with production or service provision. This includes direct costs (such as raw materials, labor, and manufacturing costs) and indirect costs (such as equipment depreciation, rent, and management expenses). The sum of these costs is typically referred to as the total cost.

**Markup:** On top of the total cost, the business adds an additional markup rate to cover other expenses and achieve the desired profit. This markup is usually expressed as a percentage or a fixed amount and takes into account factors such as market conditions, competition, target profit margin, and other relevant considerations.

**Determine Selling Price:** By adding the markup to the total cost, the business can determine the final selling price. The selling price should be sufficiently high to cover costs and achieve the desired profit level.

This method can be expressed by the following formula:

$$SellingPrice = TotalCost + (TotalCost \times MarkupRate) \tag{1}$$

### 3.2. Establishment of a Nonlinear Programming Model for Maximizing Profit

Symbol Conventions:

$l_{ij}$ is the expected sales volume for product category $j$ on the $ith$ day; $\alpha_{ij}$ represents the fluctuation factor for product category $j$, introducing perturbations to the forecasting results to increase randomness; $y_{ij}$ is the discount factor for product category $j$ on the ith day; $a_j$ is the expected wholesale price for product category $j$;$b_{ij}$ is the expected profit margin for product category j on the ith day;$d_{ij}$ is the cost-plus pricing for product category $j$ on the ith day;$c_j$ is the loss rate for product category $j$;$\beta_{ij}$ is the demand for product category $j$ on the ith day; $Ll_{ij}$ is the lower bound of replenishment quantity for product category $j$ on the $ith$ day;$Lu_{ij}$ is the upper bound of replenishment quantity for product category j on the $ith$ day.AA represents the impact of the loss rate on product demand.BB represents the impact of the expected profit margin on the demand for the product.

$$\beta_{ij} = (1+\alpha_{ij})\left(1-\frac{c_j}{3}\right)(1+y_{ij})\left(1-\frac{e^{b_{ij}-1}}{4}\right)l_{ij} \tag{2}$$

$$Ll_{ij} = (1-\ \alpha)l_{ij} \tag{3}$$

$$Lu_{ij} = (1+\ \alpha)l_{ij} \tag{4}$$

$$d_{ij} = a_j(1+b_{ij}) \tag{5}$$

$$\mathrm{AA} = \left(1-\frac{c_j}{3}\right) \tag{6}$$

$$\mathrm{BB} = \left(1-\frac{e^{b_{ij}-1}}{4}\right) \tag{7}$$

Recording the total profit for the next seven days in a supermarket and considering it as the replenishment quantity, the actual sales volume satisfies:

$$\mathrm{S_{ij}} = \begin{cases} x_{ij}, \beta_{ij} > x_{ij} \\ \beta_{ij}, \beta_{ij} \le x_{ij} \end{cases} \tag{8}$$

Based on the above analysis, we derive the corresponding model for maximizing supermarket revenue:

$$max\ z = \sum_{i=1}^{7}\sum_{j=1}^{6} F_{ij}\,S_{ij} - x_{ij}a_j \tag{9}$$

$$s.t.\begin{cases} x_{ij} \ge 0 \\ 0 \le y_{ij} \le 1 \\ Ll_{ij} \le x_{ij} \le Lu_{ij} \\ 0 \le b_{ij} \le 1 \\ F_{ij}S_{ij} - x_{ij}a_j \ge 0 \end{cases} \tag{10}$$

The independent variables are $x_{ij}$(replenishment quantity), $y_{ij}$(discount factor), $b_{ij}$(expected profit margin),and the dependent variable is the total profit $z$or the supermarket over the next seven days.

The constraints are as follows:

$x_{ij} \ge 0$ to ensure non-negativity of the replenishment quantity.

$0 \le y_{ij} \le 1$ to keep the discount factor within the range of 0 to 1.

$Ll_{ij} \le x_{ij} \le Lu_{ij}$ to ensure that the replenishment quantity $x_{ij}$ falls within the specified range.

$0 \le b_{ij} \le 1$ as the expected profit margin should be between 0 and 1. This choice is based on examining the average cost profit margins of vegetables in various provinces and major cities in China in previous years, where it was observed that the cost profit margins for vegetables did not exceed 100%.

Additionally, the constraint $F_{ij}S_{ij} - x_{ij}a_j \ge 0$is enforced to ensure that each product category is not incurring losses on a daily basis, contributing to the overall profitability of the supermarket.

Data Preparation: Analyzing the data to obtain the expected wholesale prices and expected loss rates for each product category. The Expected Wholesale Prices and Expected Category Loss Rate is shown in Table.1 and Table.2.

**Table 1.** Expected Wholesale Prices for Each Product Category

| Category | Expected wholesale price for category |
|---|---|
| Cauliflower | 5.924921089 |
| Leafy vegetables | 2.730692008 |
| Chili | 3.417191369 |
| Eggplant | 5.318794097 |
| Edible fungus | 4.265014209 |
| Aquatic root and stem | 5.81267381 |

**Table 2.** Expected Category Loss Rate

| Category | Expected wholesale price for category |
|---|---|
| Cauliflower | 0.093848371 |
| Leafy vegetables | 0.098982027 |
| Chili | 0.085299024 |
| Eggplant | 0.062870614 |
| Edible fungus | 0.038255131 |
| Aquatic root and stem | 0.093384405 |

By establishing an ARIMA model[9], this article predicted the daily sales volume for various categories in the upcoming week.

**Table 3.** The forecasted daily sales volume for various categories in the upcoming week

| Date | Cauliflower | Leafy vegetables | Chili | Eggplant | Edible fungus | Aquatic root and stem |
|---|---|---|---|---|---|---|
| 7.1 | 22.58164599 | 155.7969996 | 83.41231616 | 24.16175815 | 48.53992121 | 20.36418017 |
| 7.2 | 20.85323989 | 142.7821939 | 83.67310103 | 21.9252256 | 49.02275482 | 19.40833291 |
| 7.3 | 19.58606536 | 125.4987319 | 81.280325 | 21.15523917 | 52.04287194 | 19.6994549 |
| 7.4 | 20.99124626 | 142.8305025 | 80.91010405 | 22.01754484 | 52.48454608 | 19.89784337 |
| 7.5 | 22.09715828 | 164.8658445 | 80.31728602 | 21.24390907 | 53.82564017 | 20.04089139 |
| 7.6 | 23.17983042 | 159.3288666 | 80.66046653 | 22.05927891 | 51.85890701 | 20.15599832 |
| 7.7 | 25.05144817 | 166.7987133 | 81.01830591 | 21.3127122 | 49.99601145 | 20.26943983 |

### 3.3. Presentation of Results

This paper utilized simulated annealing algorithm[10] for solving and obtained the maximum revenue for the supermarket in the upcoming week as 4269.6 yuan. Additionally, it provided the replenishment plan and pricing strategy for the next week.

The optimal daily replenishment quantity is shown in Table.4.

**Table 4.** Optimal Daily Replenishment Quantity Matrix

| Date | Cauliflower | Leafy vegetables | Chili | Eggplant | Edible fungus | Aquatic root and stem |
|---|---|---|---|---|---|---|
| 7.1 | 20.0026 | 149.1415 | 92.5200 | 25.2995 | 54.3440 | 21.4961 |
| 7.2 | 18.2535 | 127.4776 | 76.4876 | 18.8695 | 46.8704 | 18.5635 |
| 7.3 | 18.0745 | 123.5646 | 71.0240 | 18.7617 | 44.2531 | 18.2250 |
| 7.4 | 23.3356 | 127.9968 | 77.1300 | 20.1644 | 57.8526 | 17.0958 |
| 7.5 | 23.3732 | 147.0649 | 72.1526 | 23.4376 | 56.9359 | 17.3386 |
| 7.6 | 25.9676 | 156.7791 | 82.7311 | 20.1660 | 45.7719 | 21.0252 |
| 7.7 | 27.8330 | 164.8432 | 88.6169 | 19.2392 | 54.9884 | 17.7358 |

The optimal selling price is shown in Table.5.

**Table 5.** Optimal Selling Price Matrix

| Date | Cauliflower | Leafy vegetables | Chili | Eggplant | Edible fungus | Aquatic root and stem |
|---|---|---|---|---|---|---|
| 7.1 | 11.38562 | 4.611105 | 6.222669 | 8.943911 | 7.67758 | 9.615866 |
| 7.2 | 9.966145 | 5.344312 | 6.744451 | 9.701224 | 8.302315 | 10.68333 |
| 7.3 | 9.557438 | 4.96899 | 6.551741 | 8.480282 | 8.01005 | 10.56456 |
| 7.4 | 11.45063 | 5.326514 | 6.381842 | 7.976681 | 7.336646 | 10.80574 |
| 7.5 | 10.17304 | 5.332224 | 6.48919 | 7.558694 | 7.410119 | 11.00914 |
| 7.6 | 8.967955 | 5.39207 | 6.652242 | 10.00453 | 7.716002 | 10.30804 |
| 7.7 | 11.17674 | 5.234157 | 5.966529 | 7.595163 | 7.50179 | 8.1029 |

The optimal discount factor is shown in Table.6.

**Table 6.** Optimal Discount Factor Matrix

| Date | Cauliflower | Leafy vegetables | Chili | Eggplant | Edible fungus | Aquatic root and stem |
|---|---|---|---|---|---|---|
| 7.1 | 0.0260 | 0.1403 | 0.0650 | 0.1266 | 0.0656 | 0.0979 |
| 7.2 | 0.1375 | 0.0127 | 0.0121 | 0.0540 | 0.0233 | 0.0774 |
| 7.3 | 0.1555 | 0.0899 | 0.0295 | 0.1951 | 0.0452 | 0.0378 |
| 7.4 | 0.0075 | 0.0007 | 0.0265 | 0.1966 | 0.0967 | 0.0023 |
| 7.5 | 0.1390 | 0.0213 | 0.0460 | 0.2627 | 0.1094 | 0.0210 |
| 7.6 | 0.2027 | 0.0054 | 0.0022 | 0.0047 | 0.0879 | 0.0461 |
| 7.7 | 0.0549 | 0.0260 | 0.0846 | 0.2160 | 0.1078 | 0.2069 |

The optimal target profit margin ratio is shown in Table.7

**Table 7.** Optimal Target Profit Margin Ratio Matrix

| Date | Cauliflower | Leafy vegetables | Chili | Eggplant | Edible fungus | Aquatic root and stem |
|---|---|---|---|---|---|---|
| 7.1 | 0.9729 | 0.9641 | 0.9477 | 0.9253 | 0.9265 | 0.8339 |
| 7.2 | 0.9502 | 0.9823 | 0.9978 | 0.9281 | 0.9930 | 0.9922 |
| 7.3 | 0.9101 | 0.9994 | 0.9756 | 0.9808 | 0.9671 | 0.8888 |
| 7.4 | 0.9473 | 0.9520 | 0.9183 | 0.8667 | 0.9044 | 0.8633 |
| 7.5 | 0.9942 | 0.9952 | 0.9906 | 0.9276 | 0.9508 | 0.9346 |
| 7.6 | 0.8983 | 0.9853 | 0.9510 | 0.8899 | 0.9835 | 0.8590 |
| 7.7 | 0.9959 | 0.9679 | 0.9075 | 0.8213 | 0.9715 | 0.7577 |

In addition to optimizing pricing and replenishment, the model also considers the optimal discount factor and the optimal target profit margin ratio. Since determining the target profit margin ratio is a core aspect of the cost-plus pricing method, and we believe that having the ratio determined individually might be too subjective, we treat the target profit margin ratio as a variable in the model for optimization.

## 4. Conclusions

In this paper, we first conducted a time series analysis of the sales of vegetable items, followed by a correlation analysis of each category of vegetables, and finally developed a planning model and used a simulated annealing algorithm to develop a revenue-maximizing pricing and replenishment strategy.

However, in the practical application scenarios of hypermarket platforms, the pricing and replenishment strategies for vegetable products discussed in this paper are affected by many other factors. In the future research and practical application, it can be further expanded and improved in the following aspects:

(1) Based on the replenishment strategy model proposed in this paper, brand information and market share are introduced. The replenishment strategy should be moderately tilted towards big

brands. That is, for brands with large market share, the strategy of increasing replenishment volume and shelf placement rate is adopted.

(2) We can also take customers' willingness to buy each vegetable commodity into account in the model. Through the questionnaire or other forms to collect the customer's willingness to buy goods. Increase replenishment and price increase for commodities with high willingness to buy. On the contrary, for the goods with high degree of aversion, do reduce the replenishment and lower the price appropriately. Collect the degree of customer satisfaction with a product, i.e., the extent to which the customer is willing to repurchase the product, which can be quantified as n levels based on a star system for customers to choose, as a percentage increase or decrease in the replenishment and pricing calculations.

(3) There is also a need to refine the cost data. Data on transportation costs, inventory costs, and administrative costs can be collected and added to the total costs. Collect the incoming tax percentage of sales to get net sales. Use this data to correct the revenue function to make cost-plus pricing more relevant.

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