Research On Replenishment Decision of Vegetable Commodities Based on Seasonal Decomposition Exponential Smoothing Method and Objective Programming Model

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Abstract. Vegetables are indispensable in people's daily lives and represent a high proportion of the goods sold in supermarkets and bring in a large amount of profit. Therefore, the replenishment and pricing decisions on the day of sales are particularly important. In order to make the best replenishment decision, this paper firstly solves the relationship equation between the sales volume of each vegetable category and the cost-plus ratio coefficient based on the least square fitting; secondly, considering the cyclical change of the vegetable sales volume, the seasonal decomposition of the exponential smoothing method is used to predict the demand for each vegetable category in the first week of July; lastly, the profitability optimization function of the superstore is set up: the objective function is the total profit of the superstore, and the decision variables are the daily supply of each vegetable category. The objective function is the total profit of the hypermarket, the decision variables are the daily supply of each vegetable category and the cost-plus ratio coefficient, and the constraints consider the maximum inventory of the hypermarket, the supply is greater than the demand and is less than the maximum value of the historical sales volume. The maximum daily profit and the optimal cost-plus ratio of the hypermarket are finally solved. This study has reference value for vegetable commodity replenishment decision.

Keywords: Seasonal Decomposition Index Smoothing Forecast, target planning, Vegetable replenishment.

1. Introduction

Vegetables are a class of plants or mushrooms that are used for cooking and cooking to become food and are one of the essential foods in people's daily diet. In fresh food shops or supermarkets, vegetable goods are a high proportion of goods sold and can bring a large amount of profit to fresh food superstores.In 2018, the national vegetable production reached up to 703,470,000 tonnes, which brought great profit to China's vegetable market, but at the same time, it also comes with the possibility of deterioration in the quality of vegetables. Relevant data shows that due to the lack of timely and effective preservation and utilisation, up to 80 million tonnes of vegetables rot and deteriorate each year in China. Inappropriate preservation methods and incorrect sales planning can increase the likelihood of vegetable deterioration. Proper planning can increase the profitability of supermarkets and is important for the good development of China's vegetable market.

In order to make the highest possible profit, supermarkets generally price vegetables using "cost-plus pricing", which is a method used by businesses to determine the selling price of a product or service. Cost-plus pricing is a pricing method used by businesses to determine the selling price of a product or service. It involves adding a mark-up to the cost of producing or supplying a product to obtain the final selling price. It involves applying a mark-up to the cost of producing or supplying a product in order to obtain the final selling price. This mark-up is usually a percentage of the cost, which makes the consumer pay the overheads of the business and generates a profit. generating a profit. Because supermarkets sell many different types of vegetables, with different origins, prices, and preservation methods, the best time to buy vegetables is at the end of the day, and the best time to buy vegetables is at the end of the day. The best time to buy vegetables is in the early hours of the morning, so the person in charge of the superstore has to know the demand and cost of buying without knowing exactly what the superstore needs. Therefore, the person in charge of the supermarket must, without knowing exactly the demand and cost of the supermarket, make a decision on the replenishment of vegetable products on the same day according to the historical sales of each product and the historical demand. The decision to replenish vegetables on the same day is based on historical sales and historical demand for each product. In this case, it is very important to analyse the market demand correctly.

This paper examines the optimal vegetable replenishment strategy for superstores to maximise the amount of profitability. Optimal replenishment strategies for supermarket vegetables have been a hot issue in the market.In recent years, various studies have been conducted on replenishment strategies for perishable fresh produce like vegetables using different approaches.Considering the impacts of storage time and inventory volume on the deterioration rate of fresh products, the impacts of inventory display volume on sales volume in store sales, and the short life cycle characteristics of fresh products, Shuting Liang[1] investigates the inventory strategy of retail terminals under the goal of maximizing sales profit.Le Yi[2] for non-immediate deterioration of fresh products, the study of fresh multi-species joint replenishment and delivery (JRD) optimization models and algorithms.Based on the demand forecast of perishable food products under viral marketing, Lijuan Lei[3] studied the replenishment-pricing decision of perishable food products under two scenarios of not considering price discounts and considering price discounts.Based on the assumption of linear deterioration rate of perishable products, Yanfeng Ou[4] developed a joint replenishment model for a single perishable product of multiple retailers under the assumptions of constant demand and inventory-dependent demand, respectively.Liu Yi-Zheng and Ai Xue-Yi[5] optimize investment decisions while further improving replenishment strategies through the introduction of RFID technology.Jufang Bao and Chengqian Xu[6] applied the three-parameter Weibull distribution to describe the variation of deterioration rate, and established an optimal replenishment model with optimal replenishment level as the decision variable under the premise that the demand rate varies with the price, and for the profit maximization of the enterprise as the objective function.Qiao Xue[7] proposes an infinite time-domain optimal replenishment and discounting model for the dual-shelf model with competing stochastic demand for fresh product quality decay under sales loss.Jun Chen and Kangsha[8] use the theory of metamorphic inventory to construct a joint decision model of retailers' dual-channel pricing and inventory replenishment with demand dependent on price and inventory levels.

In order to obtain the optimal replenishment and pricing strategies, firstly, regression analyses are conducted on the sales volume and cost-plus ratio of each vegetable category to explore the relationship between the total sales volume of each vegetable category and the cost-plus pricing; secondly, the exponential smoothing method is used to predict the demand volume of each vegetable category in the next seven days; lastly, an optimization model is established, the objective function is the maximization of the hypermarket's revenue, and the decision variables are the hypermarket's daily replenishment volume in the next week Total quantity and pricing, the constraints are that the daily supply is greater than the demand and less than the threshold quantity, and the sum of the daily supply of each category is less than the maximum inventory of the superstore. Finally, the total daily replenishment quantity and pricing for each category in the coming week are obtained to maximise the revenue of the hypermarket.

2. Mathematical Model Construction

2.1. Least Squares Regression Model

Pricing methods commonly used by supermarkets often refer to the cost-plus pricing method, which begins by analysing the total sales volume of each vegetable category in relation to cost-plus pricing. Cost-plus pricing is a method of setting the price of a product based on the unit cost of the product plus a percentage of the profit. It is also a method of adding a portion of profit to the cost of the product. The pricing formula is as follows:

$$P = C(1 + F) \tag{1}$$

In the formula, P is the price per unit of product, C is the cost per unit of product, and F is the cost-plus percentage. The cost-plus proportion formula was made by Excel, and finally the cost-plus proportion data for each vegetable category in June 2023 was obtained, as shown in Table 1.

Table 1: Table of Cost-Plus Ratio by Vegetable Category

Name/Time	2023/6/1	2023/6/2	2023/6/3	......	2023/6/29	2023/6/30
Cauliflower	0.38	0.35	0.39	......	0.48	0.46
Philodendron	0.46	0.54	0.58	......	0.43	0.64
Capsicum	0.97	0.79	0.74	......	0.72	0.65
Eggplant	0.56	0.54	0.64	......	0.65	0.73
Edible_mushroom	0.74	0.71	0.67	......	0.47	0.45
Aquatic_rhizomes	0.39	0.4	0.44	......	0.38	0.2

The least squares method finds the best function match by minimising the square of the error, and its formula for finding the optimal linear fit parameters is:

$$b = \frac{\sum_{i=1}^{n}(x_i - x)(y_i - y)}{\sum_{i=1}^{n}(x_i - x)^2} \tag{2}$$

$$a = \bar{y} - b\bar{x} \tag{3}$$

Least squares fitting of sales volume and cost-plus ratios for each of the six categories using Matlab's cftool toolbox yielded regression equations for the six categories of vegetables, namely cauliflower, foliar, chilli, eggplant, edible mushrooms, and aquatic roots and tubers:

$$F_1 = -0.006463M_1 + 0.6099 \quad (R_{square} = 0.2094) \tag{4}$$

$$F_2 = 0.0005621M_2 + 0.424 \quad (R_{square} = 0.1243) \tag{5}$$

$$F_3 = -0.001296M_3 + 0.8156 \quad (R_{square} = 0.1282) \tag{6}$$

$$F_4 = -0.001886M_4 + 0.6384 \quad (R_{square} = 0.6384) \tag{7}$$

$$F_5 = -0.001336M_5 + 0.4396 \quad (R_{square} = 0.1351) \tag{8}$$

$$F_6 = -0.00124M_6 + 0.3721 \quad (R_{square} = 0.3721) \tag{9}$$

In the formula, F represents the cost-plus percentage and M represents the sales volume.

From the above equation, it can be seen that the cost-plus ratio and sales volume of leafy and edible vegetables are positively proportional, which may be due to the fact that the market has an oversupply of these two types of vegetables, which ensures that sales volume can be increased at the same time as the profit; whereas the cost-plus ratio and sales volume of the other types of vegetables are inversely proportional, which indicates to a certain extent that there is sufficient supply of these types of vegetables, and that consumers tend to choose the lower-priced vegetables, resulting in a profit that is lower to some extent. In addition, since the cost-plus ratio is not only related to sales volume, but also affected by various factors such as market policy, the fit of the regression equation is lower in R-square, which coincides with the real factors.

2.2. Exponential Smoothing Combined with Seasonal Decomposition Forecasting Model

Step1. Seasonal decomposition of time series.

The time series decomposition can be used to determine the trend and seasonality of the time series with the decomposition equation [9]:

$$y_t = T_t + S_t + R_t \tag{10}$$

where T_t denotes the smoothed trend term, S_t denotes the seasonal term, and R_t denotes the residual term. For data with a strong trend, the seasonally adjusted data should move more than the residual term. For time series with no trend or a very weak trend, the two variances should be approximately the same. This introduces the strength of the trend, which is defined as:

$$F_T = \max\left(0,1 - \frac{\mathrm{Var}(R_t)}{\mathrm{Var}(T_t + R_t)}\right) \tag{11}$$

The value of F_T is between 0 - 1. Since in some cases the variance of the residual term is even larger than the seasonally transformed series, let F_T take the the minimum value of 0. The seasonal intensity is defined as follows:

$$F_S = \max\left(0,1 - \frac{\mathrm{Var}(R_t)}{\mathrm{Var}(S_t + R_t)}\right) \tag{12}$$

The purpose of seasonal decomposition is to decompose the time series into trend, seasonality and residual components for better understanding and modelling of time series data.

This paper explores the total daily replenishment and pricing strategies for the week ahead (1 July - 7 July 2023) for each vegetable category in supermarkets using historical sales data for supermarket vegetables. The daily sales volume of each category in June 2023 is counted and the daily supply volume from 1 July to 7 July is forecasted using exponential smoothing. Trend the time series of sales data before selecting the forecasting method, as shown in Figure 1:

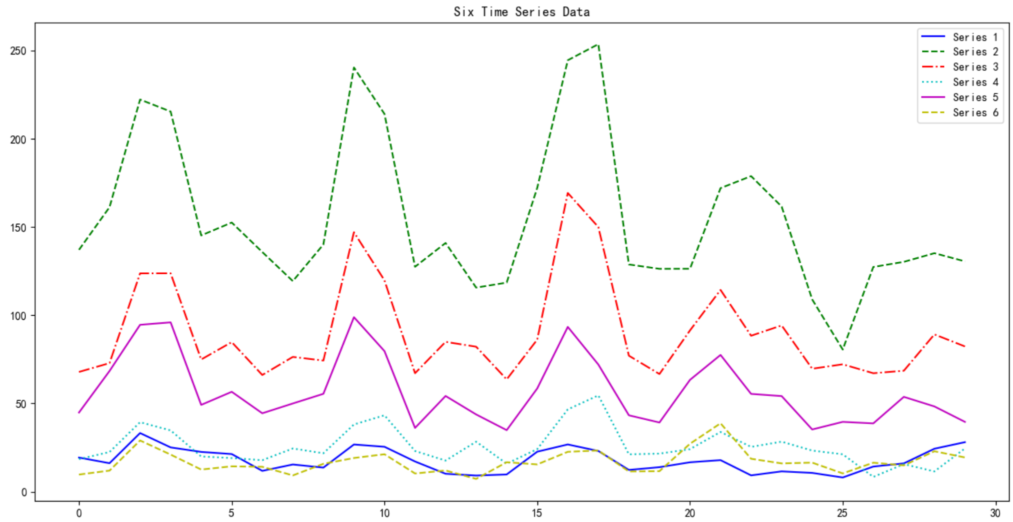

Figure 1. Chart of changes in sales of six types of vegetables

As can be seen from Figure 1, there are strong seasonal variations in the sales of all types of vegetables, so this paper chooses the exponential smoothing algorithm Combined with the seasonal decomposition of the time series to predict the data from 1 July to 7 July.

Step2. Exponential Smoothing Forecast

Exponential smoothing obtains the weights of all observations through a recursive formula and makes predictions about the future on this basis. The recursive equation of the trend-based exponential smoothing forecasting method (Holt) [10]:

$$S_t = \alpha X_t + (1 - \alpha)(S_{t-1} + b_{t-1}) \tag{13}$$

$$b_t = \beta(S_t - S_{t-1}) + (1 - \beta)b_{t-1} \tag{14}$$

The prediction formula is as follows:

$$\hat{X}_{t+h} = S_t + hb_t \tag{15}$$

S_t denotes the estimate of the level of this time series at moment t, b_t denotes the trend (slope) of this time series at moment t of the estimate, α is the smoothing parameter for the level ($0 \leq \alpha \leq 1$), and β is the smoothing parameter for the trend ($0 \leq \beta \leq 1$).

We use Python software to implement exponential smoothing forecasts combined with seasonal decomposition, and the results of seasonal decomposition and trend analysis are shown in Fig:

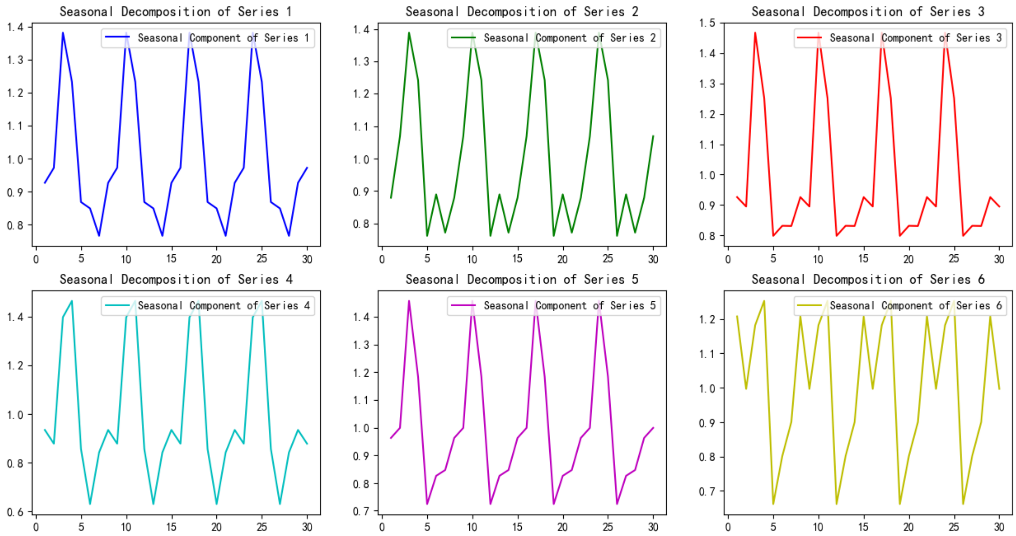

Figure 2. Seasonal Breakdown Chart

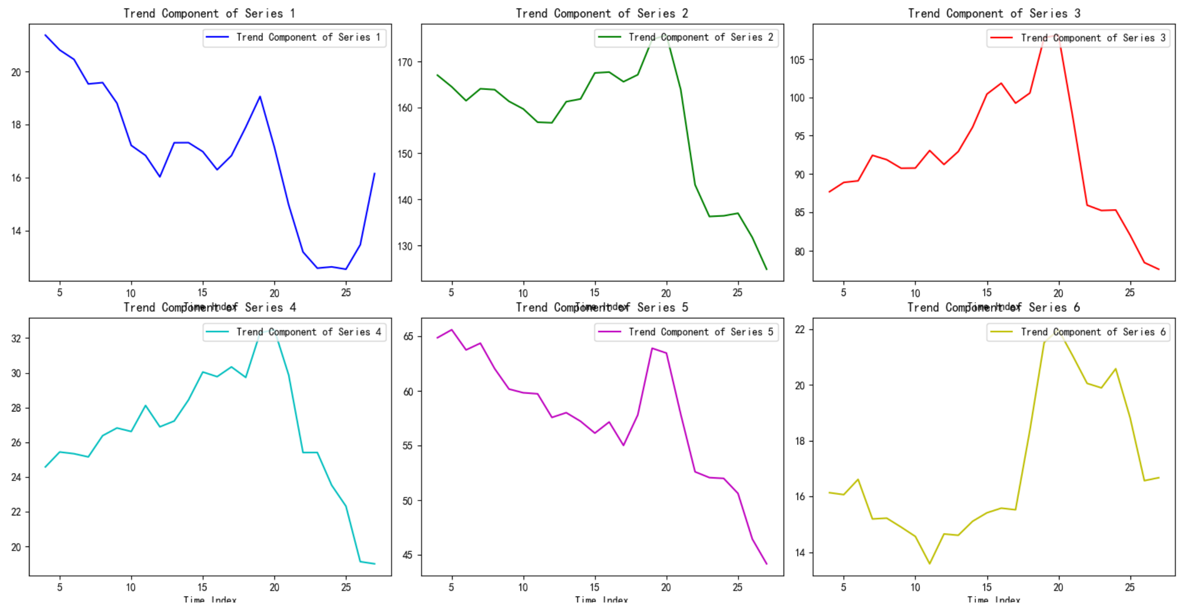

Figure 3. Trend Chart

As can be seen in Figures 2 and 3, there is a strong seasonal variation in the sales of all categories of vegetables, but the trend is difficult to determine. It has a definite trend only in a certain time period. Finally, the demand from 1 July to 7 July is predicted as shown in the table 2:

Table 2: Demand for Vegetables by Category, July 1 - July 7

Dates	Cauliflower	Philodendron	Capsicum	Eggplant	Edible mushroom	Aquatic rhizomes
2023-07-01	36.754	185.479	133.509	33.433	79.200	21.710
2023-07-02	32.960	167.312	115.731	34.392	65.040	20.542
2023-07-03	26.610	90.853	72.801	16.898	36.734	11.206
2023-07-04	26.205	108.096	75.849	12.317	42.226	13.643
2023-07-05	24.418	99.327	77.033	17.241	46.718	15.887
2023-07-06	27.589	109.531	82.268	16.924	45.719	19.488
2023-07-07	27.955	130.464	80.780	19.830	50.363	16.278

The effect of prediction was examined using the mean square error MSE to obtain the mean square error histogram:

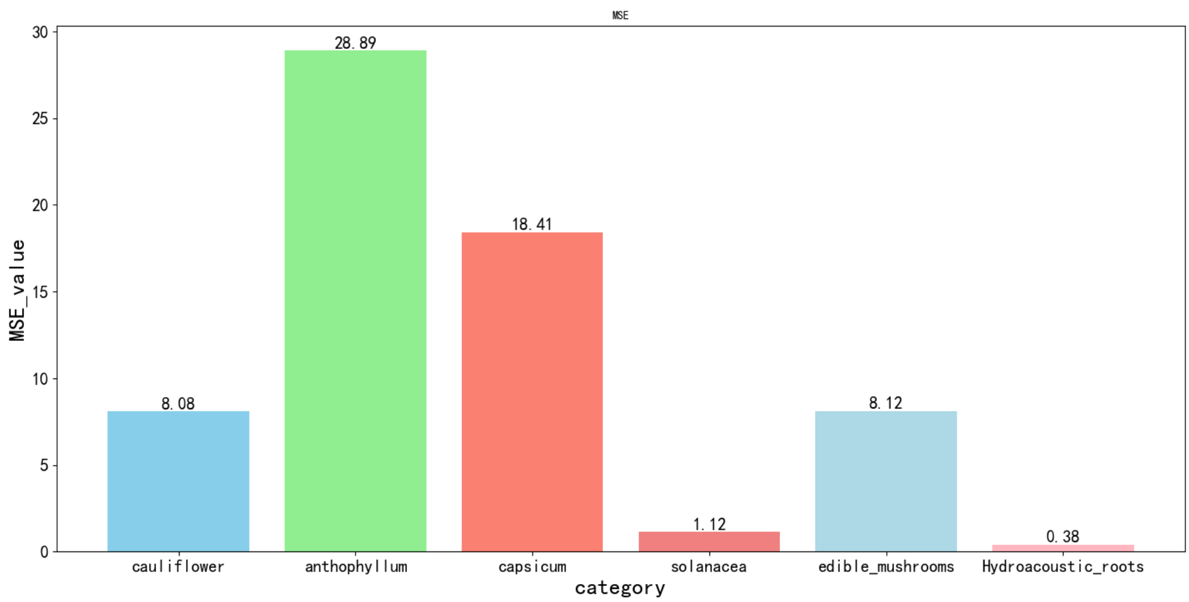

Figure 4. Histogram of mean square error.

As can be seen from Figure 4, the errors between the model predicted values and the actual values are small, and the MSEs are all within a reasonable range, indicating that it is reasonable to utilise the seasonal decomposition combined with exponential smoothing algorithm to predict the model is reasonable.

Step3. Optimal Profit Modelling

The regression equation for the ratio of sales to cost plus for each category obtained from least squares fitting:

$$F_i = f(M_i) = k_i M_i + b_i \quad i = 1,2 \dots ,6 \tag{16}$$

According to the rules of market price movements, the wholesale prices of a category of dishes will not change significantly in the short term. Therefore, consider the average cost of each category in June 2023 is considered as the unit product cost of each category in the first week of July:

$$C=\frac{\sum_{m=1}^{30}C_m}{\sum_{m=1}^{30}M_m} \quad (17)$$

Where C_m is the cost on the mth day of June and M_m is the sales volume on the mth day.

Since vegetables can be damaged during transport and preservation, it is assumed that the wastage rate of category i on day j is L_{ij}, and that the wastage rate is mainly caused by various risk factors, which are uncontrollable, and the wastage rate of a certain category will not change significantly in the short term. Therefore, consider using the average wastage rate of June to replace the average wastage rate of the week of July:

$$L_i=\frac{\sum_{m=1}^{30}\sum_{n=1}^{N_i}L_{mn}}{30} \quad (18)$$

Where N_i is the total number of individual items in category i. The total profit function can be expressed as:

$$\max r=\sum_{i=1}^{7}\sum_{j=1}^{6}P_{ij}D_{ij}-\left(C_{ij}+L_{ij}C_{ij}\right)M_{ij} \quad (19)$$

Where P represents the pricing per unit of product. Assuming that the daily supply D_i can be sold in full, i.e., $D_i = M_i$, substituting equation (16) into equation (19) yields the total profit function as:

$$\max r=\sum_{i=1}^{6}\sum_{j=1}^{7}\left(k_{ij}M_{ij}+b_{ij}-L_{ij}\right)C_{ij}M_{ij} \quad (20)$$

The constraints consider that the daily replenishment of each vegetable category is greater than the current day's demand and less than the maximum sales volume in the historical data; Considering the maximum inventory of the superstore, it is agreed that the sum of the daily supply of vegetables is less than or equal to the sum of the largest supply in the historical data, and finally quadratic programming equation is obtained:

$$\max r=\sum_{i=1}^{7}(k_iM_i+b_i-Li)C_iM_i \quad (21)$$

$$\text{s.t.}\, Q_{ij}\le M_{ij}\le \max\{M_i\} \quad (22)$$

$$\sum_{i=1}^{6}M_{ij}\le \max\left\{\sum_{i=1}^{6}M_i\right\} \quad (23)$$

Where Q_{ij} is the demand for dish category i on day j. The quadratic programming function is optimised to obtain the optimal daily supply SM_{ij}.

The optimal daily supply is the parameter to maximise profit, but the predicted daily demand does not reach the optimal daily supply. According to the optimal supply quantity of goods may lead to the supply is greater than the demand, and then make the supermarket cost loss; If according to the demand quantity of goods may lead to the If the goods are purchased according to the optimal supply quantity, it may lead to cost loss; if the goods are purchased according to the demand quantity, it may lead to failure to maximise the profit. The relationship between demand and optimal daily supply is introduced.

$$\alpha=\frac{SM-Q}{SM} \quad (24)$$

The final formula for the daily supply is obtained:

$$FM = \alpha Q + (1-\alpha)SM \tag{25}$$

Calculate the wastage rate of each category of vegetables as shown in Table 3:

Table 3: Loss Rate Calculations

Cauliflower	Philodendron	Capsicum	Eggplant	Edible mushroom	Aquatic rhizomes
14.14%	9.4%	9.5%	9.53%	9.4%	9.44%

Model optimisation using quadratic programming function of matlab yields the optimal daily supply and cost-plus ratio for each category as table 4 and table 5:

Table 4: Optimal Availability July 1 - July 7

Dates	Cauliflower	Philodendron	Capsicum	Eggplant	Edible mushroom	Aquatic rhizomes
7/1	36.754	170.388	133.509	41.155	79.402	25.910
7/2	34.269	122.102	115.731	42.566	65.336	24.312
7/3	27.936	90.174	72.801	18.873	37.069	12.327
7/4	27.376	114.486	75.849	13.368	42.459	15.309
7/5	24.596	105.169	77.033	19.307	46.718	18.147
7/6	29.201	116.354	82.268	18.914	45.809	22.892
7/7	29.640	130.454	80.780	22.570	50.364	18.648

Table 5: Optimal Cost-Plus Percentage for July 1 - July 7

Dates	Cauliflower	Philodendron	Capsicum	Eggplant	Edible mushroom	Aquatic rhizomes
July 1st	0.3724	0.5198	0.6426	0.5608	0.5457	0.34
July 2nd	0.3884	0.4926	0.6656	0.5581	0.5269	0.342
July 3rd	0.4293	0.4747	0.7212	0.6028	0.4891	0.357
July 4th	0.4330	0.4882	0.7173	0.6132	0.4963	0.353
July 5th	0.4509	0.4831	0.7158	0.6020	0.5020	0.350
July 6th	0.4212	0.4894	0.7090	0.6027	0.5008	0.344
July 7th	0.4183	0.4973	0.7109	0.5958	0.5069	0.349

Calculate the maximum in a week for each category based on wholesale price (cost), loss ratio, optimal supply quantity, and optimal cost-plus ratio Profit:

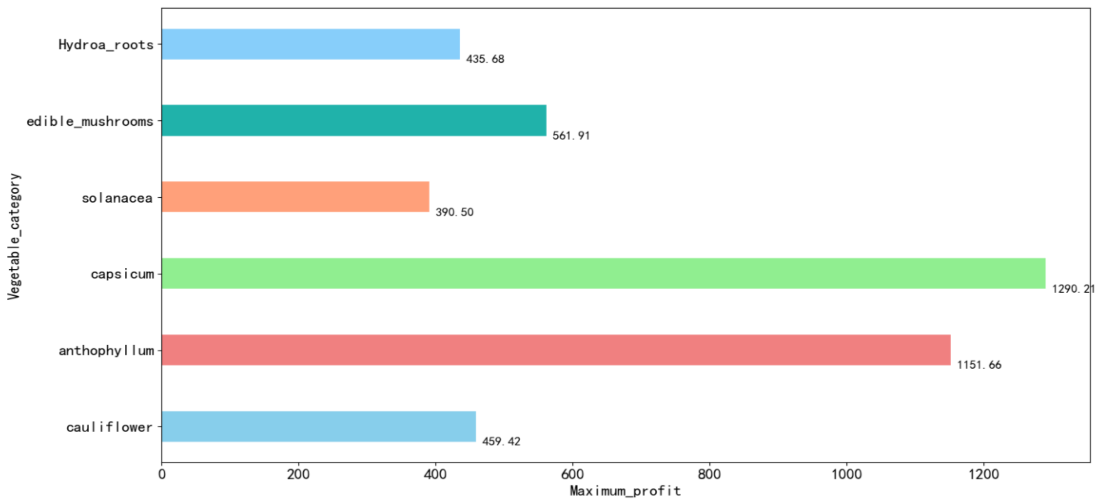

Figure 5. Maximum weekly profitability of each vegetable category

As can be seen from Figure 5, the maximum profit (yuan) of cauliflower, foliage, chilli, eggplant, edible mushrooms, and aquatic root vegetables in the first week of July were 459.42, 1,151.66, 1,290.21, 390.5, 561.91, and 435.68, respectively. The maximum profit of malls profit volume is 4289.38 yuan.

3. Conclusions

For the determination of pricing and sales quantity, firstly, the relationship between the total sales volume of different categories and cost-plus pricing is analysed using the curve fitter linear regression in the MATLAB toolbox, and it is found that the total sales volume of flowers and foliage category shows a slight positive correlation with the cost-plus pricing, whereas the other categories show a negative correlation with their cost-plus pricing; secondly, the Fourier level of curve fitter in the MATLAB toolbox is used to Secondly, use the curve fitter Fourier level in MATLAB toolbox to fit the June sales curve and calculate the degree of fit for verification, predict the sales of each vegetable category in the first week of July, calculate the daily replenishment quantity, determine the pricing of each category by using the results of linear regression, and construct the pricing decision-making optimisation model, which provides the optimal sales suggestions for each category of vegetables.

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