

# Research On LSTM-Based Pricing Strategy for Vegetable Category Wholesale Price Prediction and Multi-Objective Planning

Dan Liu<sup>1,\*,#</sup>, Zheng Zhang<sup>2,#</sup>, Yueyang Zheng<sup>3,#</sup>, Jia Yang<sup>3</sup>, Minghua Xu<sup>4</sup>,  
Lipeng Wang<sup>2</sup>, Chenrui Wang<sup>5</sup>

<sup>1</sup> College of Marine and Environmental Sciences, Tianjin university of Science and Technology, Tianjin, China, 300457

<sup>2</sup> College of Artificial Intelligence, Tianjin university of Science and Technology, Tianjin, China, 300457

<sup>3</sup> College of Economics and Management, Tianjin university of Science and Technology, Tianjin, China, 300457

<sup>4</sup> College of Electronic Information and Automation, Tianjin university of Science and Technology, Tianjin, China, 300457

<sup>5</sup> College of Chemical Engineering and Materials Science, Tianjin university of Science and Technology, Tianjin, China, 300457

\* Corresponding Author Email: liudan@mail.tust.edu.cn

#These authors contributed equally

**Abstract.** Fresh vegetable products constitute an indispensable facet of both daily life and the developmental trajectory of the food industry. Owing to the susceptibility to damage and spoilage, vegetable commodities frequently engender substantial financial losses for food retail establishments. This paper addresses the replenishment and pricing decision problem for vegetable commodities and proposes a solution based on goal programming and LSTM time series forecasting models. Firstly, historical data analysis reveals a linear or logarithmic correlation between vegetable sales volume and cost-plus pricing. Subsequently, an LSTM neural network model is employed to forecast wholesale vegetable prices for the upcoming week. Building upon the forecasted results, a multi-objective programming model is established with the objective of maximizing revenue, utilizing daily replenishment total and pricing as decision variables. The model takes into account the constrained relationship between sales volume and pricing, as well as the lower limit constraint on wholesale prices. Additionally, the paper solves the programming model using the least squares method to determine the optimal daily replenishment quantity and pricing for each vegetable category. Finally, the computational results validate the effectiveness of the proposed method in guiding replenishment and pricing decisions for supermarkets, achieving revenue maximization. This study provides a feasible quantitative decision-making solution for supermarkets facing complex replenishment and pricing issues.

**Keywords:** LSTM Time Series, Forecasting Multi-Objective, Planning Vegetable Pricing.

## 1. Introduction

Vegetables are an indispensable part of People's Daily life. However, due to its short shelf life, it is prone to damage and deterioration, which affects sales and brings certain losses to businesses. The variety of vegetables is rich, and the production area is numerous, and the supermarket must make the replenishment decision of the day in advance according to the historical sales and demand of vegetables and complete the transaction within the specified time. The pricing of vegetables generally adopts the "cost plus pricing" method, but due to the short shelf life of vegetables, the product grade deteriorates with the increase of sales time; Goods are also worn out from transport to sale. For the difference and loss of vegetables, businesses often choose to sell at a discount. In the case of increasingly fierce competition in the fresh market, it is particularly important to formulate the best

replenishment and pricing plan according to the relationship between supply and demand. Therefore, in China, the retail industry urgently needs more practical and effective models in the field of pricing and replenishment control. Under the strategy of price discount and inventory stimulation, a price discount and inventory control model for a variety of beer products based on demand forecasting was established [1]. Considering the freshness of the products, a dynamic pricing strategy and replenishment policy for multiple batches of fresh agricultural products matching the real-time freshness were developed [2,3]. Since some vegetable products have the characteristics of general price and time-dependent seasonal demand rate, SnigdhaBanerjee and AshishSharma considered a deterministic inventory model [4]. To solve this problem, this paper takes a product category as the research object, combines the wholesale price and cost-plus pricing of products, and according to the data provided by the mathematical contest in modeling, firstly adds and averages the wholesale price and loss rate of each product, then fits the function between the total sales volume of vegetable categories and cost-plus pricing. Finally, according to the objective function of revenue maximization, A multi-objective programming model is established for solving [5].

## 2. Main content

### 2.1. Vegetable category sales volume analysis

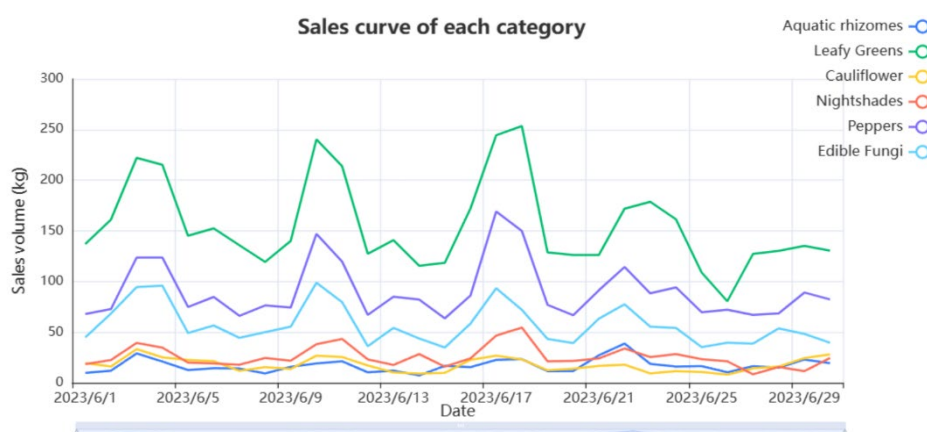


Figure 1. Daily sales of vegetables

BP neural network is a multi-layer network with error reverse propagation, which is composed of input layer nodes, hidden layer nodes and output layer nodes. This process has been reduced to an acceptable level of error to the network output, or to a predetermined number of learning times. The network structure is shown in Figure 1.

Based on the data attached to Question C of the National Mathematical Contest in Modeling for College Students in 2023, this paper uses statistical analysis methods to make the daily sales changes of six categories of vegetables in June 2023, so as to further analyze the weekly distribution law of vegetable sales. It can be seen from Figure 1 that the daily sales volume of each vegetable category presents a wave crest line. The peak occurred on Saturday, followed by sales on Friday and again on Sunday, mainly due to the impact of passenger traffic. The results show that the three categories with the largest weekly sales volume are flower and pepper, and the weekly sales volume of the top three vegetable categories is roughly the same. The sales volume of edible fungi, nightshade, cauliflower and aquatic rhizomes fluctuated slightly, and the trend was stable. The difference in the sales volume of different vegetable categories is mainly affected by people's dietary preferences and supply. From the point of view of the specific sales volume, the weekly sales volume of Mosaic vegetables is roughly [100,250], the sales volume of chili vegetables is roughly [70,160], the sales volume of edible fungi is roughly [40,100], and the sales volume of nightshade, cauliflower and aquatic roots is roughly [0,50].

## 2.2. Determination of the relationship between vegetable sales volume and cost plus pricing

Next, we will further analyze the relationship between the sales volume of vegetable products and the cost-plus pricing. On the premise of ensuring the maximum profit of the supermarket, we will establish a linear programming model and solve it step by step to work out the best replenishment plan and pricing strategy. Cost plus pricing method [6] is a pricing method commonly used by enterprises. By consulting relevant materials, we establish the relationship between cost plus pricing method, vegetable wholesale price and vegetable loss rate, and obtain the cost pricing relationship formula.

$$x_i = \frac{p_i}{1 - s_i} \quad (1)$$

Where  $x_i$  refers to the pricing obtained by using the cost-plus pricing method,  $p_i$  is the wholesale price, and  $s_i$  is the attrition rate. Considering that there may be a linear or logarithmic relationship between the total sales volume of vegetable products and the cost-plus pricing, the model between the total sales volume of vegetable products and the cost-plus pricing is established as follows.

$$\begin{cases} q_i = ax_i + b \\ q_i = a \ln x_i + b \end{cases} \quad (2)$$

Through the data given by the mathematical contest in modeling, we fit the linear function and logarithmic function relationship between the total sales volume and pricing of six major vegetable categories and determine the optimal functional relationship between the sales volume of each vegetable category and the cost-plus pricing.

Aquatic rhizomes:

$$q_i = 567.1101963363045 \ln x_1 - 1.187534390650601 \arcsin \theta \quad (3)$$

Cauliflower

$$q_i = -4.780927797658365x_2 + 82.0302645047677 \quad (4)$$

Edible Fungi:

$$q_i = -11.150713237894145x_3 + 162.85733015182754 \quad (5)$$

Leafy Greens:

$$q_i = 581.8782039844558 \ln x_4 - 0.7021918897099201 \quad (6)$$

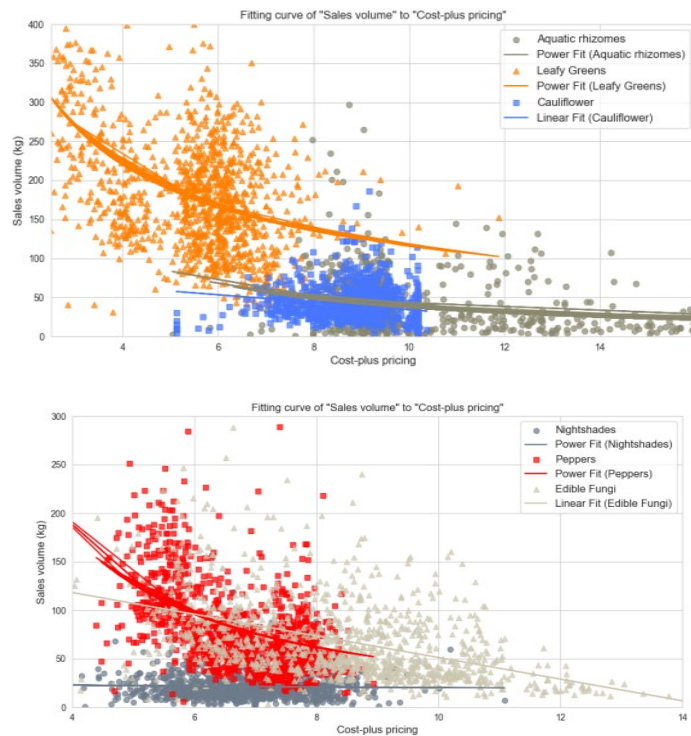
Nightshades:

$$q_i = 27.3486099496846 \ln x_5 - 0.12936927375207197 \quad (7)$$

Peppers:

$$q_i = 1471.7078078470631 \ln x_6 - 1.5245265023301156 \quad (8)$$

At the same time, the fitting relationship between the total sales volume and pricing of each vegetable category is obtained, as shown in Figure 2.



**Figure 2.** The fitting relationship between sales volume and pricing of vegetable category

### 2.3. Establishment of model

We take the total amount of daily replenishment and daily pricing of each vegetable category in the coming week as the decision variables, that is,  $y_i$  is the total amount of daily replenishment and  $x_i$  is the daily pricing obtained through the cost-plus pricing method. After comprehensively considering the impact of the total amount of daily replenishment and daily pricing on the revenue of supermarket [7], the objective function expression is constructed as follows.

$$\max \sum_{i=1}^n y_i, i = 1, L, 6 \tag{9}$$

$$y_i = q_i * x_i - r_i * p_i \tag{10}$$

Among them, the dependent variable  $y_i$  represents the income of the  $i$ -vegetable category on that day,  $q_i$  represents the sales volume of the  $i$ -vegetable category on that day, and  $p_i$  represents the wholesale price of the vegetable category on that day.

In order to fully meet the consumer demand of customers and ensure the shopping experience of customers, the daily replenishment amount of each vegetable category should not be less than the total sum of the day's sales and losses. At the same time, in order to protect the earnings of the supermarket, the pricing should not be lower than the wholesale price, that is, the cost price [8].

To sum up, the profit maximization model of commercial surplus is as follows.

$$\max y_i, i = 1, L, 6 \tag{11}$$

$$s.t. \begin{cases} r_i \geq q(x_i) + r_i * s_i \\ x_i \geq p_i \end{cases} \tag{12}$$

### 2.4. Model solving

For the task of predicting wholesale prices from July 1 to 7, 2023, a long short-term memory neural network (LSTM) was adopted [9]. In the data preprocessing stage, spline interpolation method is used to fill the missing values in the data set to ensure that the model can have more complete and coherent

time series information during training. Considering that the data is presented on a weekly basis, the time step is set to 7 to more accurately capture this periodic feature.

The data is divided into a training set and a test set, with a proportion of 85%, and is normalized to improve the stability and effect of model training. In the configuration of the neural network model, a total of 1200 epochs were trained, with each batch size of 128. When constructing the LSTM network, the Adam optimizer is selected, and the mean square error (MSE) is used as the loss function. The hierarchy of the model consists of two LSTM layers, each containing 100 neurons. The first LSTM layer has an input time step of 11, an input dimension of 1, and is set to return complete sequence information. This is followed by a Dropout layer with a drop rate of 20% to reduce the risk of overfitting the model. The second LSTM layer that follows also contains 100 neurons but returns only the final output. Finally, a dense layer with a linear activation function is introduced to output the forecast results of wholesale prices.

After the model training is completed, the rolling window method is used to predict gradually, and the input sequence is constantly updated with the last value of the current input sequence as the starting point to obtain the model prediction results. After the reverse normalization, the prediction results of wholesale price are finally obtained. The line chart of predicting wholesale price by LSTM for each vegetable category is shown in Figure 3. The predicted wholesale price list of each vegetable category is shown in Table 1.

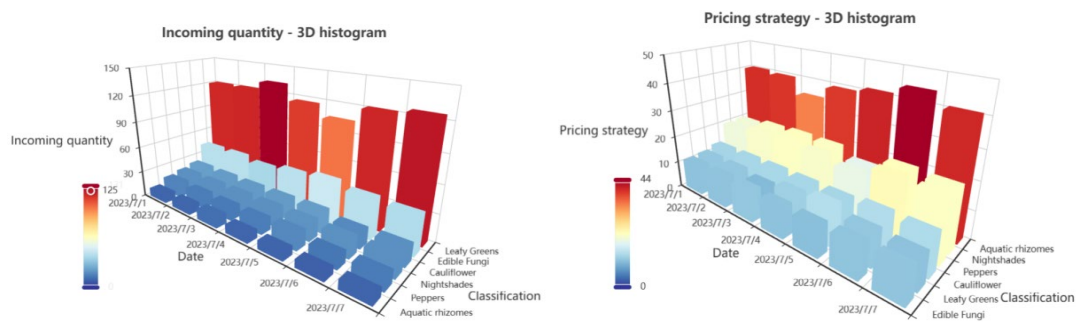


Figure 3. Vegetable category sales forecast chart

**Table.1.** Pricing strategy sheet

Date	Classification name	Wholesale prices pre	Date	Classification name	Wholesale prices pre
2023/7/1	Aquatic rhizomes	13.349805	2023/7/1	Nightshades	6.721548
2023/7/2		13.146158	2023/7/2		7.1667023
2023/7/3		11.342098	2023/7/3		7.312532
2023/7/4		13.050058	2023/7/4		7.2394223
2023/7/5		13.6567745	2023/7/5		6.194491
2023/7/6		14.750077	2023/7/6		7.429601
2023/7/7		13.521292	2023/7/7		7.207564
2023/7/1	Leafy Greens	3.8472633	2023/7/1	Nightshades	6.628517
2023/7/2		3.8121626	2023/7/2		7.0672116
2023/7/3		3.4099894	2023/7/3		7.251144
2023/7/4		4.112169	2023/7/4		7.0591803
2023/7/5		4.684676	2023/7/5		6.3733225
2023/7/6		3.8191183	2023/7/6		7.5520625
2023/7/7		3.666935	2023/7/7		7.241338
2023/7/1	Cauliflower	7.67894	2023/7/1	Edible Fungi	6.9278197
2023/7/2		7.8784623	2023/7/2		6.909587
2023/7/3		8.040272	2023/7/3		7.4738407
2023/7/4		7.9885287	2023/7/4		6.8235035
2023/7/5		7.8068876	2023/7/5		6.230425
2023/7/6		9.2309675	2023/7/6		6.922827
2023/7/7		8.7834215	2023/7/7		7.218783

Finally, we applied the least square method [10] to solve the established model and obtained the replenishment volume and pricing strategy of the next 7 days. In order to make the result data clearer and more definite, we drew a 3D map of the relationship between the date and each vegetable category and the replenishment volume and pricing, and made a replenishment plan based on the category, so as to maximize the profit of supermarket. We give the relationship between replenishment volume and pricing from July 1 to 7 in the future, as shown in Figure 4. In short, we successfully used LSTM neural network to process the time series data, realized the accurate prediction of the next 7 days wholesale price, and used the least square method to solve the model, improving the reliability of the results.



**Figure 4.** 3D histogram of purchase quantity and pricing strategy

As can be seen from the figure, compared with other vegetable categories, flowers and leaves have more replenishment volume and lower pricing, which are low-profit and high-marketable products, and are the main income source of supermarket. Aquatic roots and stems have less replenishment

volume and lower pricing, which are scarce products, and are the main competitive products of this supermarket compared with other supermarkets.

According to the above calculation, the quantity of replenishment and the pricing strategy can be obtained, and the profit maximization of the supermarket can be obtained by the formula of the supermarket profit maximization model. The results are shown in Table 2. It can be seen that the maximum daily profit of the maximization profit in each vegetable category is flowers and leaves, 974.49 yuan, the smallest profit for cauliflower.

**Table.2.** Maximum profit in vegetable category

Classification name	Maximum profit
Aquatic rhizomes	275.7921023890341
Cauliflower	119.53855122473061
Edible Fungi	213.27245336826138
Leafy Greens	974.4907991748015
Nightshades	291.2309480159014
Peppers	227.52449371194024

### 3. Conclusions

The variety of vegetables is rich, and the production area is numerous, and the supermarket must make the replenishment decision on the same day in advance according to the historical sales and demand of vegetables. In order to work out the best replenishment and pricing scheme, this paper first uses the data fitting method based on the sales volume and cost-plus pricing data of each category to obtain the corresponding relationship expression between sales volume and cost-plus pricing. Secondly, according to the existing wholesale price sum and the corresponding time series data, the wavelet neural network and LSTM time series prediction model about the wholesale price and the corresponding date of each product are established, and the wholesale price of each product in the next week is predicted. Finally, an objective function with the goal of maximizing revenue is established and solved by the least square method to obtain the replenishment quantity and pricing of each category in the next week.

### References

- [1] Wang Y., Gao H., Xing W. (2018) Optimal replenishment and stocking strategies for inventory mechanism with a dynamically stochastic short-term price discount. *Journal of Global Optimization*, 70(1), 27-53.
- [2] Gao J.-J., Ting K. (2009) Joint decision model of inventory control and promotion optimization based on demand forecasting. *Proceedings of the 2009 IEEE International*.
- [3] Li Yali. (2023) Joint replenishment and pricing coordination strategy for considering fresh technology investment [D]. *Chongqing jiaotong big science*.
- [4] Hong G.H., Park S.C., Jang D.S., Rho H.M. (2005) An effective supplier selection method for constructing a competitive supply-relationship. *Expert Systems with Applications*, 28(4), 629-639. *Conference on Automation and Logistics, ICAL, 2009*, art. no. 5262965, 119-123.
- [5] Angy. (2021) Research on Pricing of Science and Technology Research Services based on cost plus cost pricing. *Library Research and Work*, 2021(10), 25-31+24. (in Chinese).
- [6] Lu Shuqiang. (202) *Algorithm Innovation and Practical Application of Mathematical Modeling -- Review of Mathematical Modeling Algorithm and Application (3rd Edition)*. *Modern Radar*, 44(03), 111.
- [7] Pan Xiaofei, Xie Zhiheng, Wang Shuyun. (in Chinese) (202) Optimal decision of fresh products' super preservation effort and pricing considering loss avoidance. *Highway Transportation Science and Technology*, 39(06), 177-185+190.
- [8] Lu Jing. (2021) Research on storage control and dynamic pricing of raw and fresh agricultural products [D]. *Tianjin great learning*.

- [9] Iftikhar, Hasnain & Zafar, Aimel & Turpo, Josue & Rodrigues, Paulo & Lopez-Gonzales, Javier Linkolk. (2023) Forecasting Day-Ahead Brent Crude Oil Prices Using Hybrid Combinations of Time Series Models. *Mathematics*, 11, 3548.
- [10] Caruntu, Bogdan. (2021) Approximate Analytical Solutions for Systems of Fractional Nonlinear Integro-Differential Equations Using the Polynomial further Squares Method. *The highest-resolution and Fractional*, 5, 198. 10.3390 / fractalfract5040198.