Vegetable replenishment and pricing model for supermarkets based on BP neural network and planning model

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Abstract. Vegetable goods in the superstore have high freshness requirements, in order to make the maximum profit under the condition of meeting the market demand, it is necessary to determine the total amount of replenishment as well as the pricing strategy. This paper applies BP neural network to establish a model to get the relationship between vegetable sales and cost-plus pricing. Finally, the objective function is constructed with the maximum profit, and a planning model is established to determine the total amount of replenishment in the coming week and formulate the pricing strategy with the maximum profit. It aims to solve practical problems and help superstores better determine the replenishment volume and pricing strategy of vegetables.

Keywords: Planning Models, BP Neural Networks, Pricing Strategies.

1. Introduction

When it comes to the preservation of vegetables, supermarkets need to keep an eye on the freshness of vegetables as their quality deteriorates over time. Supermarkets will predict the replenishment varieties and quantities for the next day based on historical sales data to keep the shelves fresh. In addition, supermarkets can improve their operational efficiency by means of market research, introducing intelligent management systems and establishing good relationships with suppliers. Usually, supermarkets restock between 3am and 4am. During this time period, supermarket staff need to complete replenishment work quickly and accurately. Staff often cannot know in advance the varieties and unit prices of the vegetables that are about to be replenished. Therefore, they need to make quick decisions based on historical data and market conditions to determine reasonable replenishment quantities and prices[1]. Through market research, supermarkets can find out which vegetable varieties are more popular with consumers and which ones need further improvement in quality. In addition to market research, supermarkets can also improve operational efficiency by introducing intelligent management systems. For example, by using an intelligent inventory management system, supermarkets can monitor the inventory of vegetables in real time and make timely replenishment to avoid stock-outs or backlogs. At the same time, an intelligent sales system can help supermarkets better analyse sales data and provide stronger support for decision-making. This paper establishes a superstore vegetable replenishment and pricing model based on a planning model through data cleaning, significance analysis, descriptive analysis, Spearman correlation analysis, hierarchical clustering and grey correlation analysis[2-3].The model considered various factors such as vegetable sales volume, sales unit price, cost, and wastage rate, and a bp neural network was used for training to obtain the relationship between vegetable sales volume and cost-plus pricing. Zhao Xin et al. established the Topsis model to evaluate the factors affecting vegetable sales and pricing, and obtained the linear fitting function between the total sales volume and various indicators, and thus obtained the relationship between cost-plus pricing and total sales volume.[4].In addition, supermarkets can improve the quality and freshness of vegetables by establishing a good relationship with suppliers. Regular communication with suppliers to understand their production situation ensures that suppliers can provide vegetables that meet the standards in a timely manner.The model of this paper is built by means of a prediction model[5]and a neural network model[6-7].

2. BP neural network and planning model building

2.1. Modelling the relationship between sales volume and cost-plus pricing

Superstores need to set reasonable prices while restocking vegetables, and usually, superstores use the cost-plus pricing method to price goods, which is easy to operate and accurate. This paper needs to study the relationship between vegetable sales and cost-plus pricing in depth and analyse the correlation between them.

Firstly, the category's percentage of daily sales is obtained from the relationship between single item sales in a single day and total sales in a single day:

$$\mathrm{bl} = \frac{\text{Sales volume of a single item on a single day}}{\text{Total sales volume in a single day}} \tag{1}$$

The analysis reveals that either the average price or cost per day is related to the category's percentage of daily sales, with the following relationship equation:

$$\mathrm{price} = \bar{\mathrm{p}} \cdot \mathrm{bl} \tag{2}$$

$$\mathrm{cost} = \mathrm{TC} \cdot \mathrm{bl} \tag{3}$$

Where is the weighted pricing; is the average price per day; is the category cost-plus price; and is the total cost. The resulting expression for cost-plus pricing is obtained after analysis.

2.2. Evaluation indexes of bp neural network training results and model results

The data is brought into the neural network model for training, with multiple iterations to reduce the error and make the data analysis more accurate

The learning process of BP neural network is divided into two stages [8]: forward propagation stage and back propagation stage. In the forward propagation phase, the input signal is passed in from the input layer, processed in each layer, and finally passed to the output layer and the output result is obtained.Based on the problem of unreasonable platform pricing in the modern logistics industry, Do Yu Ang conducted grey correlation analysis and cluster analysis to explore the main factors affecting pricing, and created a BP neural network optimization model based on the above results to give an accurate and effective platform pricing scheme.[9]. If the output result is consistent with the desired result, the learning ends; otherwise, it enters the reverse propagation phase. In the back-propagation stage, the weights and thresholds of each layer are adjusted according to the error between the output result and the desired result, so that the output of the network is gradually close to the desired output.

BP neural network has the characteristics of self-learning, self-organisation and adaptability [10], so it has a wide range of applications in pattern recognition, prediction, classification and so on. The input layer of the neural network model is the input variable and the output layer is the variable to be obtained. At the time of inputting the data, the data goes to the next layer i.e. the hidden layer by linking the weights.

2.3. Model training

Taking the relationship between vegetable sales and cost-plus pricing as an example, we have trained the relevant data by using a neural network model. By using the neural network model to train the data, the smaller the error is, the more real and effective the established model is. The final relationship equation between vegetable sales and cost-plus pricing is obtained as follows:

$$\mathrm{y} = 0.75 \cdot \mathrm{x} + 18 \tag{4}$$

This relationship shows that there is a linear relationship between vegetable sales (y) and cost-plus pricing (x) under certain conditions. Where 0.75 is a linear coefficient representing the sensitivity of sales volume to cost-plus pricing and 18 is a constant term representing the baseline sales volume when cost-plus pricing is not considered.

The discovery of this relational equation has important practical implications. For vegetable suppliers, they can develop a more scientific pricing strategy based on this relational equation, so as to increase the sales volume, reduce the cost, and achieve better economic efficiency. At the same time, this also proves the great potential of neural network models in solving practical problems.

Overall, neural network models have significant advantages in handling complex data and revealing hidden patterns. Through continuous learning and optimisation, we have reason to believe that neural networks will play their unique value in more fields.

2.4. Planning model

2.4.1 Construction of the objective function

In order to meet the market demand, and make the superstore profitability is maximised, the sales data of vegetables in the last quarter is the object of study, and the objective function is constructed.

Supermarket profitability is divided into three main components, namely, the original selling price y1, the discounted selling price y2 and the cost price y3:

$$\begin{cases} y_1 = 0.7x(1-0.01\varepsilon \times s_v) \\ y_2 = (1-0.01\varepsilon \times s_v) \\ y_3 = cost \times s_v \end{cases} \tag{5}$$

The final constructed objective function was:

$$z_{max} = y_1 + y_2 - y_3 \tag{6}$$

$$z_{max} = 0.7x(1-0.01\varepsilon \times s_v) + x(1-0.01\varepsilon \times s_v) - cost \times s_v \tag{7}$$

Where is the supe$_r$store profit amount; is the loss rate of vegetable goods; is the replenishment quantity, obtained by applying the trained bp neural network; 0.7 is the discount discount set in this paper.

2.4.2 Construction of constraints

Constraints are established based on historical pricing records, i.e., pricingmust not be greater than the previous quarter's pricing maximum,and at the same time must not be less than the previous quarter's pricing minimum,.This establishes the constraints as follows:

$$s.t. \quad lb < x < ub \tag{8}$$

2.4.3 Determining replenishment volume modelling

$$z_{max} = 0.7x(1-0.01\varepsilon \times s_v) + x(1-0.01\varepsilon \times s_v) - cost \times s_v \tag{9}$$

$$s.t. \quad lb < x < ub \tag{10}$$

The model is a neural network-based vegetable replenishment and pricing model, which established a model for the relationship between the sales volume of vegetable categories and cost-plus pricing by analysing the historical sales data, and used bp neural network for training to obtain the relationship between vegetable sales volume and cost-plus pricing. The model also established a model for determining the replenishment quantity, which maximised the profitability of the superstore by constructing the objective function and constraints.

3. Results

3.1. Solving the cost-plus pricing model

In order to formulate the pricing strategy for July 1-7, 2023, this article selected the sales data of the previous four weeks as a reference. The study found that there is a certain pattern in the weekly

sales volume, so you can choose the unit price of some vegetables sold every 7 days and find the average value. Then, through the relationship model between vegetable sales volume and cost-plus pricing established above, the cost-plus price in the coming week is analyzed and determined, as shown in Table 1:

Table 1 Cost-plus prices for different categories of vegetables in the coming week Unit (RMB/kg)

	mosaic species	cauliflower	aquatic rhizomes	eggplant	chili peppers	edible mushrooms
1day	3.43	9.73	10.15	4.96	3.48	3.46
2day	3.47	9.40	10.69	4.89	3.45	3.60
3day	3.44	9.01	11.38	4.81	3.50	3.69
4day	3.53	9.37	11.73	4.88	3.44	3.44
5day	3.39	9.38	11.79	4.76	3.38	3.30
6day	3.29	9.41	11.21	5.20	3.65	3.69
7day	3.27	9.22	10.84	4.96	3.54	3.53

3.2. BP neural network model training results

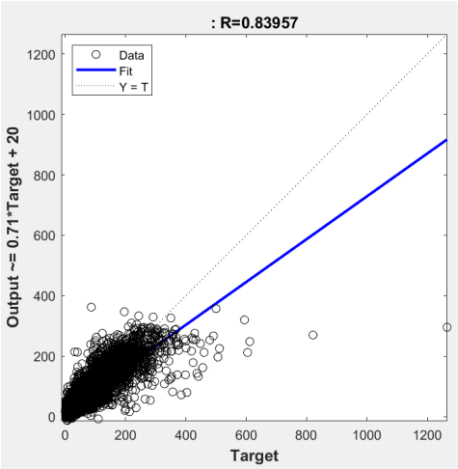


Figure 1 Neural network training regression graph

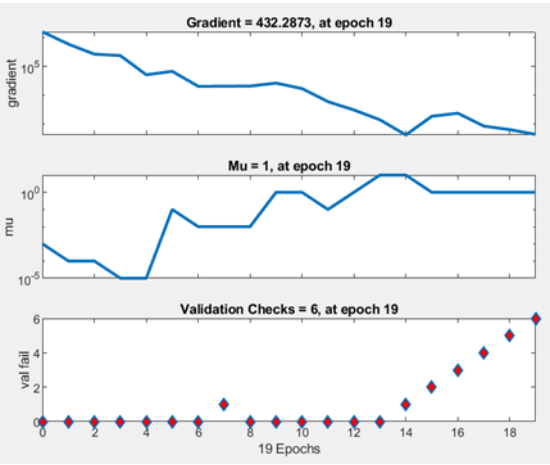


Figure 2 The state of the neural network training value

Figure 1 showed the regression of the neural network model's goals for test set, training, and validation in the form of regression diagrams. After analysis, it is found that the data basically decreases along the 45° oblique line in the figure, indicating that the output of the neural network is basically consistent with the target, and the R value is above 0.83957.

Figure 2 showed the status of the training values, from top to bottom, the gradient plot, the MU plot, and the validation parameters, i.e., the weighted parameters in which they are trained.

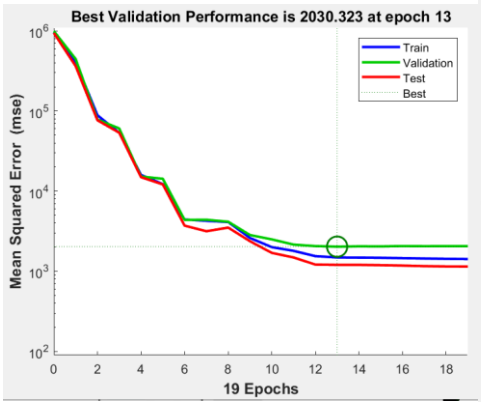


Figure 3 Neural network training histogram

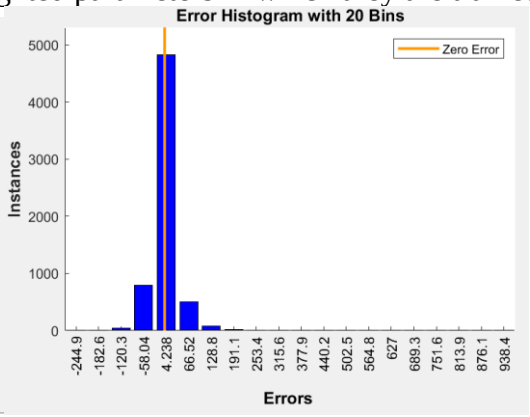


Figure 4 Training mean square deviation and number of iterations plots

Figure 3 showed one of the most important indicators of the training results of the neural network model, the Error histogram, in the form of a histogram, where the blue rectangle represents the training data, and it can be seen that most of the errors are between -10 and 10.

Figure 4 illustrates the indicator Promance. The analysis showed that after training, the error determined by the mean variance is 2030.323, and the number of iterations is 13.

3.3. BP neural network model solution results

It is mainly used to judge the reasonableness of the neural network model, mainly based on the three indicators of Regression, Error histogram and Promance, and it is found that the neural network model established in this paper is reasonable and useful.

By using a neural network model to train the data, the smaller the error, the more realistic and effective the model is. In the end, the relationship between vegetable sales volume and cost-plus pricing is as follows:

$$y = 0.75 \cdot x + 18 \tag{11}$$

According to the established model, the vegetable sales data of the previous quarter were taken as the research object, and the final replenishment quantity was determined as follows, as shown in Table 2:

Table 2 The number of replenishments for different categories of vegetables

	mosaic species	cauliflower	aquatic rhizomes	eggplant	chili peppers	edible mushrooms
Total Replenishment (kg)	5.87	14.49	12.61	9.55	7.97	7.55

3.4. The planning model solves and determines the replenishment quantity

Based on the established model, the sales data of the previous quarter were used as the research object, and the final replenishment quantity (as shown in Table 3) and pricing strategy (as shown in Table 4) were determined:

Table 3 Finalize the replenishment quantity of different categories of vegetables in the coming week Unit (kg)

	mosaic species	cauliflower	aquatic rhizomes	eggplant	chili peppers	edible mushrooms
1day	201.68	32.33	31.05	21.00	89.81	97.93
2day	198.94	32.04	30.39	20.18	90.33	94.25
3day	180.20	32.74	28.16	26.25	82.41	82.69
4day	167.83	27.38	21.30	30.80	88.37	68.78
5day	178.65	29.40	25.02	26.80	83.68	82.14
6day	191.60	31.03	27.08	21.05	82.91	90.79
7day	175.89	33.63	27.86	27.54	80.31	76.93

According to the experimental results, it was found that the demand for mosaic and leaf replenishment was the largest, and the daily replenishment volume was more than 160 kg. Nightshade replenishment 1 requires the least amount of replenishment, with a daily replenishment of about 25 kg. After analysis and verification, the planning model can be applied to the actual vegetable replenishment plan to determine.

Table 4 Finalize the pricing strategy for the different categories of vegetables in the coming week
Unit (kg/yuan)

	mosaic species	cauliflower	aquatic rhizomes	eggplant	chili peppers	edible mushrooms
1day	5.55	15.20	15.51	4.96	7.30	6.40
2day	5.48	15.08	14.91	4.89	7.20	6.84
3day	5.79	15.20	17.95	5.78	7.51	6.65
4day	5.51	15.20	19.03	7.87	7.72	6.49
5day	5.50	15.20	17.88	6.79	7.83	6.21
6day	5.31	15.02	15.93	5.20	7.27	6.65
7day	5.87	14.87	17.38	5.74	7.97	7.55

According to the experimental results, the analysis showed that the daily pricing of mosaic and hydroacoustic rhizome vegetables was higher, while that of mosaic and nightshade vegetables was lower.

4. Conclusions

By combining BP neural network and planning model, this paper successfully determines the total amount of vegetable replenishment and pricing strategy of supermarkets. This method can not only effectively improve the operational efficiency of supermarkets, but also help supermarkets better meet market demand, so as to maximize profits. Compared with the traditional time series prediction model, the machine learning method used in this paper can predict the nonlinear impact, and has better analysis results for difficult-to-mine data types such as vegetable sales, which is more realistic and reliable. However, at the same time, there are some shortcomings in this paper, in order to facilitate analysis, this paper simplifies the relationship model between sales volume and cost-plus pricing, and can use the method of predicting data to make simple predictions as improvements.

In general, the replenishment and pricing strategy of supermarket vegetables based on BP neural network and planning model can help supermarket operators manage vegetable sales more scientifically and improve business efficiency. Of course, in practical application, it also needs to be adjusted and improved according to the specific situation to adapt to the changes in the market and the change in demand.

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