

Optimisation of superstore single product replenishment and pricing strategy based on LSTM neural network and weighted multi-objective planning

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Abstract. Vegetable items in supermarkets usually have a short shelf life and their quality gradually deteriorates over time. Therefore, supermarkets usually need to make daily vegetable replenishment decisions based on historical sales data and demand. The purpose of this paper is to investigate the replenishment strategy and pricing strategy of individual items under many constraints in order to reach the goal of maximising supermarket revenue and market demand. Firstly, the original sales volume data is preprocessed to calculate the sales volume of each single item within 24-30 June, excluding the single item with 0 sales volume, the remaining 49 single items; secondly, the LSTM neural network model is established to predict the non-discounted sales volume, the discounted sales volume, and the cost of each single item on 1 July, respectively, and excluding the single item with total sales volume lower than 2.5 kg on 1, the remaining number of saleable single items is 32; finally, considering the three possibilities of the existing supply and demand relationship, a weighted multi-objective planning model is established to solve for each single item separately, and the optimal solution is selected from it. The results show that the maximum profit of the superstore on 1 July is 886.56 yuan.

Keywords: Vegetable replenishment and ordering, LSTM neural network, weighted multi-objective planning.

1. Introduction

Vegetable items in supermarkets usually have a short shelf life and their quality gradually deteriorates over time[1]. Therefore, supermarkets usually need to make daily vegetable replenishment decisions based on historical sales data and demand. Vegetable stocking is concentrated between 3am and 4am, and merchants need to decide how to replenish vegetable items without knowing the specific individual items and stocking prices. Vegetable pricing is usually based on a cost-plus pricing method. For vegetables that are damaged in shipping and deteriorated in quality, shopping malls usually use discounting to sell them[2-3]. This paper examines the relationship between sales and cost-plus pricing for the vegetable category when supermarkets replenish on a category basis and gives the total daily replenishment and pricing strategy for each category from 1 to 7 July 2023 to maximise the superstore's revenue. Data from <http://www.mcm.edu.cn/>.

2. Modelling and solving

2.1. Individual product quantity control

In this paper, firstly, the normal vegetable sales volume of 24-30 June 2023 is excluded, the remaining 49 single items, and secondly, using the Spearman correlation coefficient to explore the 49 single items found that there is a correlation between the normal vegetable sales volume, the discounted vegetable sales volume and the cost, and therefore, the LSTM neural network model is

established, respectively, using the 49 single items of the seven days of normal sales volume, the discounted sales volume and the finished product to predict the normal sales volume, the discounted sales volume and the finished product for the 49 single items at the 1st of July[4-5]. The LSTM neural network model is built to predict the normal sales volume, discounted sales volume and finished products of 49 individual products on 1st July. The correlation coefficients are shown in Figure 1 below:

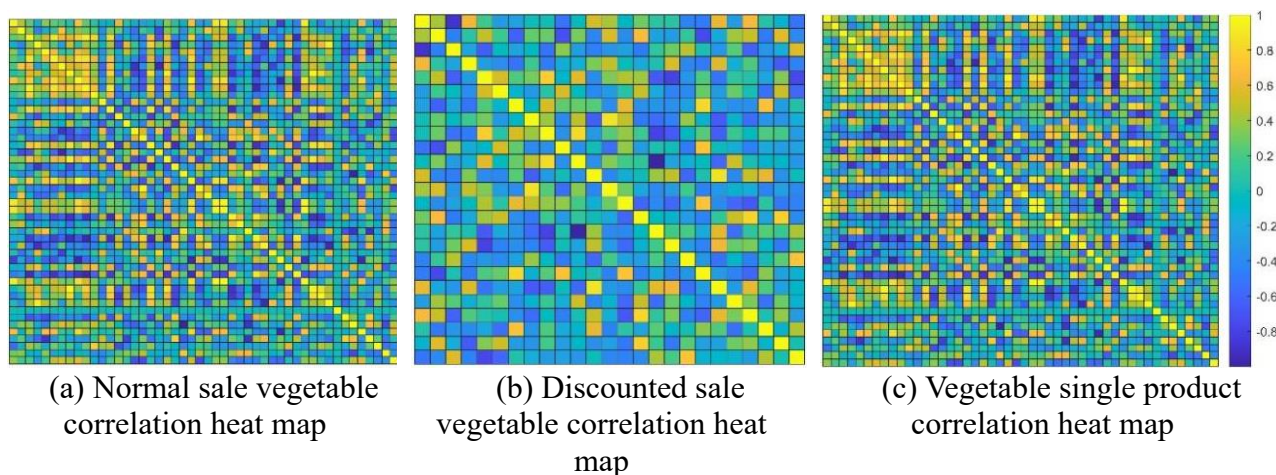


Figure 1. Correlation heat map

From the graph, it is found that 49 items have high correlation in normal vegetable sales volume, discounted vegetable sales volume and cost, with correlation coefficients greater than 0.5 in most cases. Some of these items do not have discounted sales, so there are only 25 items in the correlation coefficient graph for discounted vegetable sales volume[6].

2.2. LSTM neural network model

In this paper, the LSTM neural network prediction model is used to predict the data of July 1. The LSTM neural network prediction model is improved based on the traditional recurrent neural network model, by adding three control links of input gate, output gate and forgetting gate to the traditional RNN neural network model, the three gates can selectively memorise the data, so that the LSTM model can better deal with the time sequence tasks[7-8].

The LSTM neural network model decides which information in the cell state is to be discarded or retained or output through the forgetting gate, input gate and output gate[9-10].

The LSTM neural network parameters are set in Table 1 below:

Table 1. Parameter setting table

Parameter	settings	Parameter	settings
Maximum number of training rounds	200	Gradient maximum threshold	0.4
Initial learning rate	0.3	Learning rate descent factor	0.01
Number of learning rate drop cycles	800	Number of samples per batch	64
Learning Rate Mode	piecewise	Time series length	longest
Data shuffling	never		

A comparison of the predicted results is shown in Figure 2:

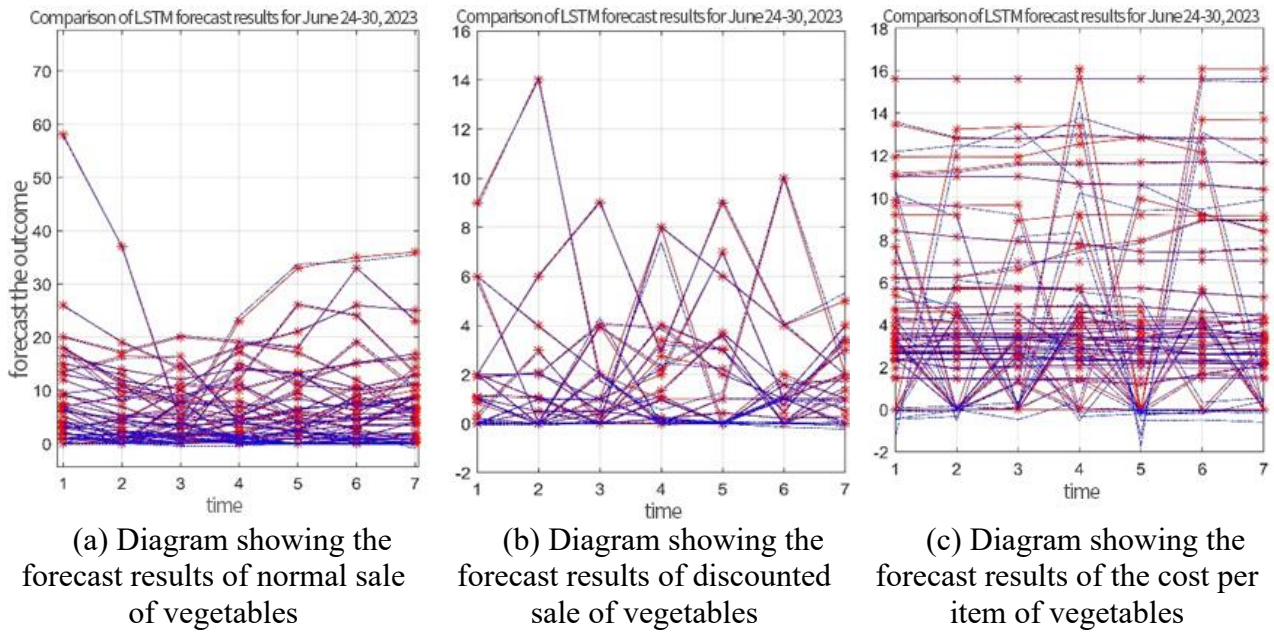


Figure 2. Graph of LSTM prediction results

From the figure, it is found that the three predictions fit well with the actual values, and the mean square error and root mean square error are less than 0.5, most of which are less than 0.01, which is low enough to be used.

The normal vegetable sales as well as discounted vegetable sales of 49 individual items were predicted, then summed and sorted, and the items smaller than 2.5 kg were excluded, and finally 32 items were retained.

2.3. Weighted dual-objective planning model

The second possibility of replenishment in the amount of normal vegetables and discounted vegetables are more than the market demand, the possibility will lead to waste, so the possibility of the maximum benefit scheme does not exist, for the remaining three possibilities, are established to solve the weighted bi-objective programming model, and ultimately choose the optimal solution.

Step1: Determination of the objective function

The objective function is to find the single vegetable sales profit gain the maximum and replenishment and the minimum difference between the predicted sales.

For the first possibility, the objective function formula is as follows:

$$\text{Max } Z = Q \times (1 - e) \times p_1 + Q \times e \times p_2 - Q \times m \quad (1)$$

$$\text{Min } W = Q - K_1 - K_2 \quad (2)$$

In the formula, $Q \times (1 - e)$ denotes the quantity of normal vegetables in the replenishment quantity; p_1 denotes the normal vegetable pricing; $Q \times e$ denotes the quantity of vegetables that need to be sold at a discount in the replenishment quantity; p_2 denotes the discounted vegetable pricing; $Q \times m$ denotes the total cost; K_1 denotes the demand for normal vegetables in the market; and K_2 denotes the demand for discounted vegetables in the market.

For the third possibility, the objective function formula is as follows:

$$\text{Max } Z = K_1 \times p_1 + Q \times e \times p_2 - Q \times m \quad (3)$$

$$\text{Min } W = Q - K_1 - K_2 \quad (4)$$

In the formula, K_1 denotes the normal vegetable demand in the market; p_1 denotes the normal vegetable pricing; $Q \times e$ denotes the amount of vegetables that need to be sold at a discount in the replenishment quantity; p_2 denotes the discounted vegetable pricing; $Q \times m$ denotes the total cost; and K_2 denotes the demand for discounted vegetables in the market.

$$\text{Max } Z = Q \times (1 - e) \times p_1 + K_2 \times p_2 - Q \times m \quad (5)$$

$$\text{Min } W = Q - K_1 - K_2 \quad (6)$$

Where, $Q \times (1 - e)$ denotes the quantity of normal vegetables in the replenishment quantity; $Q \times (1 - e)$ denotes normal vegetable pricing; K_2 denotes the demand for discounted vegetables in the market; p_2 denotes the pricing of discounted vegetables; $Q \times m$ denotes the total cost; K_1 denotes the demand for normal vegetables in the market.

Step2: Determination of constraints

For the first possibility, the constraints are as follows:

$$Q \times (1 - e) \leq K_1 \quad (7)$$

In the formula, K_1 indicates the normal vegetable demand in the market; $Q(1 - e)$ indicates the normal vegetable quantity in the replenishment quantity.

$$Q \times e \leq K_2 \quad (8)$$

Where $Q \times e$ denotes the amount of discounted vegetables in the replenishment quantity; K_2 denotes the amount of discounted vegetables demanded in the market.

$$p_2 \leq s \times p_1 \quad (9)$$

Where, p_2 denotes discounted vegetable pricing; s denotes discount rate, based on the historical average discount; p_1 denotes normal vegetable pricing.

$$p_1 \leq p_3 \quad (10)$$

Where p_1 denotes normal vegetable pricing; p_3 denotes the historical maximum price for this type of product.

$$m \leq p_1 \leq 2m \quad (11)$$

Where m denotes unit cost; p_1 denotes normal vegetable pricing

For the third possibility, the constraints are as follows:

$$K_1 \leq Q \times (1 - e) \quad (12)$$

$$Q \times e \leq K_2 \quad (13)$$

$$p_2 \leq s \times p_1 \quad (14)$$

$$p_1 \leq p_3 \quad (15)$$

$$m \leq p_1 \leq 2m \quad (16)$$

$$Q \times (1 - e) \leq K_1 \quad (17)$$

$$K_2 \leq Q \times e \quad (18)$$

$$p_2 \leq s \times p_1 \quad (19)$$

$$p_1 \leq p_3 \quad (20)$$

$$m \leq p_1 \leq 2m \quad (21)$$

Step3: Weighting

The objective function of the two functions to establish a single objective planning equation, the constraints remain unchanged, the resulting solution is the final weighted dual-objective planning equation weights.

Step4: Weighted dual-objective planning equation

The first possible objective planning equation is as follows

$$\text{Max } Z = l_i \times [Q \times (1 - e) \times p_1 + Q \times e \times p_2 - Q \times m] \quad (22)$$

$$\text{Min } W = h_i \times (Q - K_1 - K_2) \quad (23)$$

$$s. t. \begin{cases} Q(1 - e) \leq K_1 \\ Q \times e \leq K_2 \\ p_2 \leq s \times p_1 \\ p_1 \leq p_3 \\ m \leq p_1 \leq 2m \end{cases} \quad (24)$$

The third possible target planning equation is as follows:

$$\text{Max } Z = l_i \times [K_1 \times p_1 + Q \times e \times p_2 - Q \times m] \quad (25)$$

$$\text{Min } W = h_i \times (Q - K_1 - K_2) \quad (26)$$

$$s. t. \begin{cases} K_1 \leq Q(1 - e) \\ Q \times e \leq K_2 \\ p_2 \leq s \times p_1 \\ p_1 \leq p_3 \\ m \leq p_1 \leq 2m \end{cases} \quad (27)$$

The fourth possible target planning equation is as follows:

$$\text{Max } Z = l_i \times [Q \times (1 - e) \times p_1 + K_2 \times p_2 - Q \times m] \quad (28)$$

$$\text{Min } W = h_i \times (Q - K_1 - K_2) \quad (29)$$

$$s. t. \begin{cases} Q(1-e) \leq K_1 \\ K_2 \leq Q \times e \\ p_2 \leq s \times p_1 \\ p_1 \leq p_3 \\ m \leq p_1 \leq 2m \end{cases} \quad (30)$$

2.4. Optimisation results selected

At the same time, in order to comprehensively consider the impact of the types of vegetables on the superstore's revenue, this paper calculates the revenue when the total number of items sold is 27-32, respectively, and the final histogram of the total profit of each saleable item is shown in Figure 3 below:

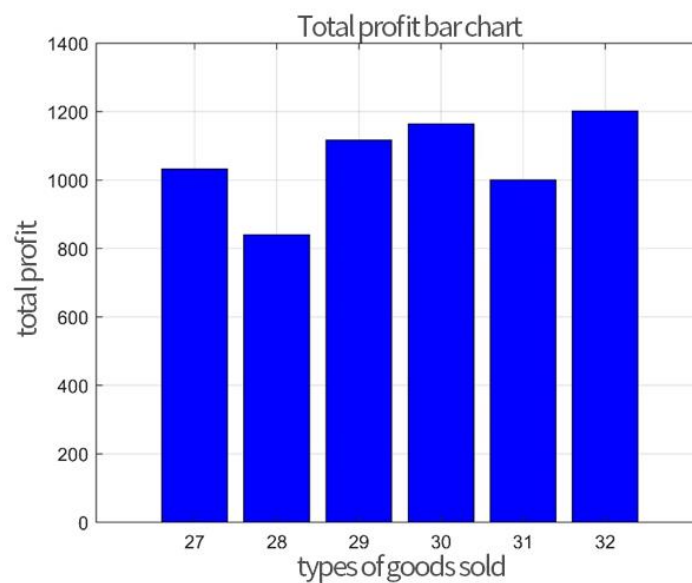


Figure 3. Histogram of total profit

By solving the above planning equations, the optimal solution is chosen to be the final solution for each item when the saleable items are 32, as shown in Table 2 below (Due to space constraints, only some of the results are shown) :

Table 2. Replenishment of final sale items and pricing table

Single Product Name	Indicators	1st July	Single Product Name	Indicators	1st July
Yunnan Lettuce(portion)	Replenishment	86.91	Yunnan Oil Wheat Vegetable(portion)	Replenishment	30.84
	Normal Pricing	7.04		Normal Pricing	5.78
	Discount Pricing	3.52		Discount Pricing	2.89
Millet Pepper(1)	Restocking Volume	21.27	Golden Needle Mushroom(box)	Restocking Volume	25.86
	Normal Pricing	4.55		Normal Pricing	2.90
	Discount Pricing	2.27		Discount Pricing	1.45
Wuhu Green Pepper(1)	Restocking Quantity	19.48	Purple Eggplant(2)	Restocking Quantity	18.99
	Normal Pricing	6.14		Normal Pricing	7.65
	Discount Pricing	3.07		Discount Pricing	3.83
Seafood Mushroom(Pack)	Restocking Quantity	11.20	Small Wrinkled Skin(portion)	Restocking Quantity	21.98
	Normal Pricing	3.91		Normal Pricing	2.88
	Discount Pricing	1.95		Discount Pricing	1.44
Bamboo Leaf Lettuce	Restocking Quantity	19.04	Screw Pepper(portion)	Restocking Quantity	14.74
	Norma Pricing	4.71		Normal Pricing	6.16
	Discount Pricing	2.36		Discount Pricing	3.08
Agaricus bisporus(box)	Restocking Quantity	22.01	amaranth greens (genus Amaranthus)	Restocking Quantity	15.52
	Normal Pricing	6.80		Normal Pricing	4.67
	Discount Pricing	3.40		Discount Pricing	2.34

Note: The unit of replenishment is kg, retain two decimal places

Pricing unit for the dollar, retain one as a decimal

Calculations show that the maximum gain for the superstore on 1 July was \$886.56

3. Conclusions

The paper investigates the problem of controlling the number of single items in superstores. Firstly, the single items with zero sales were excluded from the normal vegetable sales, leaving 49 single items, and the Spearman correlation coefficient analysis revealed that these single items were correlated in terms of normal sales, discounted sales and cost. Then, the LSTM neural network model was used to predict the sales on the 1st of July using normal sales, discounted sales and cost over a seven-day period. The results of the study showed a high correlation between these individual items in terms of different sales. The article also details the structure and parameter settings of the LSTM neural network, as well as the four steps of the model, which include acquiring information from the hidden state, selecting forgotten and retained information, updating the memory state and predicting the future with new data. The prediction results show that the LSTM model fits the sales situation well. In terms of maximising the revenue of the superstore, the article develops a weighted bi-objective planning model, which considers the sales volume of normal and discounted vegetables as well as the cost under different possibilities. Through the determination of weights and the setting of constraints, the optimal solution that can sell 32 individual products is finally selected to maximise the total profit of the superstore.

The final calculations show that the superstore has a maximum gain of \$886.56 on the 1st of July. The article provides a detailed restocking volume and pricing table of individual products, which provides a strong reference for the decision-making of the superstore.

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