Optimization Of Replenishment and Sales Strategies of Vegetable Commodities Based on Multiple Linear Regression and Non-Linear Programming

Xiangkun Fu #, *, Xiangshi Li #, Wenhuizi Wang #

Xi'an University of Architecture and Technology, Xi'an, China, 710054

* Corresponding Author Email: 18700719144@163.com

#These authors contributed equally.

Abstract. Automated pricing of vegetable items generates suggested selling prices for the items based on the provided item data, considering the structure of the data. The aim of this paper is to better help superstores plan future replenishment volumes and pricing strategies by analysing sales data for each category and individual item in the vegetable category. Specifically, this paper takes the category as a unit, uses the processed cost-plus pricing, sales volume, purchase price, and loss rate data of each vegetable category to establish a linear regression model, and based on the least squares method, the relationship between cost-plus pricing and total sales volume of each vegetable category is fitted to solve the problem, and the multivariate linear relationship expression with high fit is obtained; based on the cost-plus pricing rule, the future replenishment volume and pricing decision is established based on each category. Based on the cost-plus pricing rule, a nonlinear programming model is established based on the total daily replenishment and pricing decision for each category in the coming week, with the revenue of the superstore as the optimization objective, and considering the constraint of the transport loss rate, the total daily replenishment in the coming week under the maximal revenue is solved by using MATLAB to get the corresponding replenishment strategy, and then the total daily replenishment is substituted into the multivariate linear expression to calculate the corresponding pricing strategy.

Keywords: Cost-plus pricing, least squares fitting, non-linear programming models, superstore sales strategy.

1. Introduction

Vegetable products in fresh food superstores generally have a short shelf life [1], and their quality will deteriorate with the increase of sales time, and most of the varieties cannot be sold the next day if they are not sold on the same day. Therefore, supermarkets will be replenished every day according to the historical sales of individual products and demand [2-3].

Because of the many varieties of vegetables sold in supermarkets and the fact that vegetables are often purchased and traded in the early hours of the morning from 3:00 a.m. to 4:00 a.m., merchants are unable to accurately know the specific items and their prices, so they need to make the replenishment decision for each vegetable category on the same day. Vegetable pricing is generally based on the "cost-plus pricing" method [4-5], and supermarkets usually offer discounts on items with shipping losses and deterioration in quality. Replenishment and pricing decisions depend on reliable market demand analyses. From the demand side, the sales volume and sales time of vegetable products have a certain correlation; in this paper, we do the replenishment plan by category, analyse the relationship between the total sales volume of each vegetable category and cost-plus pricing, and give the total daily replenishment volume and pricing strategy of each vegetable category in the coming week (1-7 July 2023), so as to make hypermarkets gain the most benefits [6].

2. Linear regression model based on the relationship between total sales and cost-plus pricing by category

2.1. Data handling

Calculate daily revenue, cost, profit margin, transport loss rate, etc. using the attached data on an individual product basis.

2.2. Modelling

To analyse the relationship between the total sales volume of each vegetable category and the cost-plus pricing, the cost-plus pricing here is considered as the historical selling price of each category. As can be seen from the question, vegetable pricing is generally used "cost-plus pricing" rule, while the supermarkets have transport losses and poor-quality vegetables are usually sold at a discount, so this paper will take into account the transport losses and the cost of goods and other factors on the pricing of vegetables [7-8].

It should be noted that supermarkets make replenishment decisions for each category of vegetables on the same day based on historical demand without identifying specific individual items and purchase prices; and replenishment decisions have a significant impact on cost-plus pricing, i.e., supermarkets replenish at 3 to 4 a.m., and the amount of replenishment affects subsequent pricing of the vegetable category. Therefore, the causal relationship of this question is: historical sales data → replenishment decision → pricing decision [9-10].

Least squares are a mathematical optimisation technique that seeks to match the best function of the data by minimising the sum of squares of the errors and can be used for curve fitting.

Based on this a linear regression model is developed as follows for correlation analysis.

$$\begin{aligned} & y_{i,j} = \alpha x_{i,j} + \gamma c_{i,j} + \mu T_{i,j} + \beta \\ & i = 1,2,3,\cdots,7 \\ & j = 1,2,3,\cdots,6 \end{aligned} \tag{1}$$

Where α, γ and μ are the coefficients of the independent variables, β is the coefficient of the constant term, $x_{i,j}$ denotes the total sales volume of vegetables in category j on day i, $c_{i,j}$ denotes the cost of entry, i.e., the wholesale price of vegetables in category j on day i, $T_{i,j}$ denotes the amount of transport loss in category j on day i, $y_{i,j}$ denotes the pricing of vegetables in category j on day i, and the vegetables in category " " from category 1 to category 6 are cauliflower, foliage, chilli, eggplant, edible fungi, and aquatic rootstalks, respectively.

2.3. Model solution

To address the relationship between total sales and cost-plus pricing for each vegetable category, this question shows the final solution results using chilli vegetables as an example. The processed data were solved using MATLAB to obtain the linear regression results as shown in Table 1 below:

Table 1 Linear regression results for the chilli group (n=91)

	UNSTANDARDISED COEFFICIENT		STANDARDISED COEFFICIENT	T	P	R^2	F
	B	standard error	Beta				
CONSTANT	0.462	0.145	-	3.181	0.002***	0.978	F=1291.269 P=0.000***
INLET PRICE	-0.153	0.031	-0.102	-4.912	0.000***		
SALES VOLUME	0.001	0	0.021	1.24	0.218		
LOSS PRICE	1.019	0.02	1.055	51.597	0.000***		
DEPENDENT VARIABLE: PRICING							

Note: ***, **, * represent 1 per cent, 5 per cent and 10 per cent significance levels, respectively.

After analysis, the overall regression coefficient is not zero, indicating that there is a regression relationship between the variables. From the F-test results, the significance P-value is 0.000***, which is a significant level, rejecting the original hypothesis that the regression coefficient is zero, so the model basically meets the requirements, and obtains the expression of the linear relationship between total sales of chilli and cost-plus pricing as follows:

$$y_{i,Chili} = 0.001x_{i,Chili} - 0.153c_{i,Chili} + 1.019T_{i,j} + 0.462 \tag{2}$$

The expression for the linear relationship between total foliage sales and cost-plus pricing is shown below:

$$y_{i,Flowers\ and\ leaves} = 0.153c_{i,Flowers\ and\ leaves} + 0.857T_{i,Flowers\ and\ leaves} + 0.206 \tag{3}$$

The expression for the linear relationship between total edible mushroom sales and cost-plus pricing is shown below:

$$y_{i,Edible\ fungus} = 1.415x_{i,Edible\ fungus} + 0.003c_{i,Edible\ fungus} - 0.305 \tag{4}$$

The expression for the linear relationship between total eggplant sales and cost-plus pricing is shown below:

$$y_{i,Eggplant} = 1.012x_{i,Eggplant} - 0.11c_{i,Eggplant} - 0.002T_{i,Eggplant} + 0.611 \tag{5}$$

The expression for the linear relationship between total aquatic rootstock sales and cost-plus pricing is shown below:

$$y_{i,Aquatic\ rhizomes} = 0.033x_{i,Aquatic\ rhizomes} + 0.305c_{i,Aquatic\ rhizomes} + 0.619T_{i,Aquatic\ rhizomes} - 1.495 \tag{6}$$

The expression for the linear relationship between total cauliflower sales and cost-plus pricing is shown below:

$$y_{i,Cauliflower} = -0.338x_{i,Cauliflower} + 2.564c_{i,Cauliflower} - 0.049T_{i,Cauliflower} - 0.125 \tag{7}$$

2.4. Model checking

In order to get a more intuitive linear expression, SPSSPRO was used to plot the linear relationship for chilli vegetables as follows Fitting effect Figure 1.

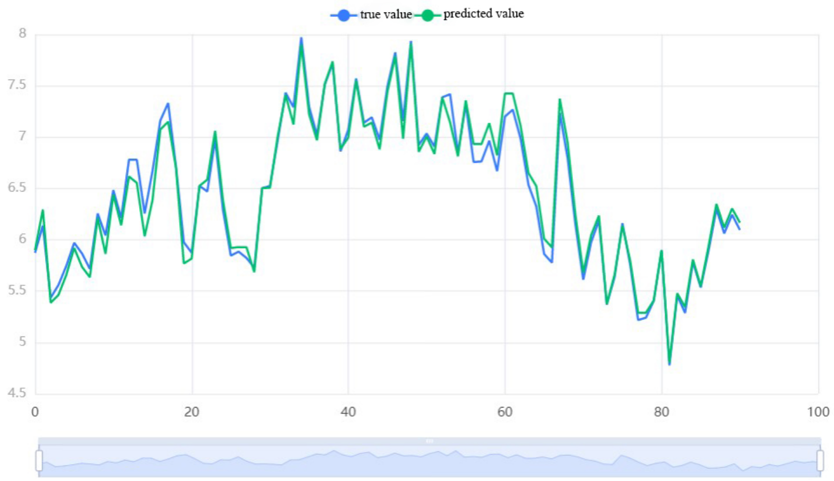

Figure. 1 Fitting effect diagram

The linear regression model can be tested using the above graph, and the true values are in high agreement with the predicted values, indicating that the model is feasible.

3. Planning model based on total daily replenishment and pricing strategy for each category for the coming week

3.1. Cost Plus Pricing Method

For information, cost-plus pricing is a pricing method that uses full cost as the basis for pricing and is illustrated by the formula:

$$\begin{aligned} &\textit{Forecast total profit} = \textit{cost profit margin} \times \textit{forecast total cost} \\ &\textit{Unit cost price} = \textit{unit product cost} \times (1 + \textit{cost profit margin}) \end{aligned} \tag{8}$$

3.2. Modelling

Identification of decision variables.Set the decision variable to be $x_{i,j}, i = 1,2,3,\cdots,7; j = 1,2,3,\cdots,6$.

Determine the objective function:

$$W_{\text{总}} = \sum_{i=1}^{7}\sum_{j=1}^{6} W_{i,j} - \sum_{i=1}^{7}\sum_{j=1}^{6} T_{i,j} \tag{9}$$

Determining constraints:

$$y_{i,j} = c_{i,j}\left(1 + w_{i,j}\right) \tag{10}$$

$w_{i,j}$ indicates the daily cost margin for each category.

Total daily profit by category:

$$W_{i,j} = w_{i,j} \cdot x_{i,j} \cdot c_{i,j} \tag{11}$$

Daily transport losses by category:

$$T_{i,j} = t_{i,j} \cdot x_{i,j} \cdot c_{i,j} \tag{12}$$

Relationship between category sales and pricing:

$$y_{i,j} = \alpha_j x_{i,j} + \gamma_j c_{i,j} + \mu_j T_{i,j} + \beta_j \tag{13}$$

Largest sales in category history:

$$x_{i,j} \le x_{\max} \tag{14}$$

The values in the formula are processed to obtain the historical maximum daily sales for each category.

In summary, the planning model is obtained as:

$$\max \quad W_{total} = \sum_{i=1}^{7}\sum_{j=1}^{6} W_{i,j} - \sum_{i=1}^{7}\sum_{j=1}^{6} T_{i,j}$$

$$s.t.\begin{cases} y_{i,j} = c_{i,j}\left(1+w_{i,j}\right) \\ W_{i,j} = w_{i,j}\cdot x_{i,j}\cdot c_{i,j} \\ T_{i,j} = t_{i,j}\cdot x_{i,j}\cdot c_{i,j} \\ y_{i,j} = \alpha_j x_{i,j} + \gamma_j c_{i,j} + \mu_j T_{i,j} + \beta_j \\ y_{i,j}, W_{i,j} \ge 0 \\ x_{i,j} \le x_{\max} \\ w_{i,j} \in R \\ i = 1,2,3,\cdots,7 \\ j = 1,2,3,\cdots,6 \, It\ means\ cauliflower, \\ flower\ and\ leaf\ respectively, \\ Peppers,\ eggplants,\ edible\ fungi, \\ Aquatic\ rhizomes \end{cases} \tag{15}$$

3.3. Model solution

The solution process is shown in Figure 2 below:

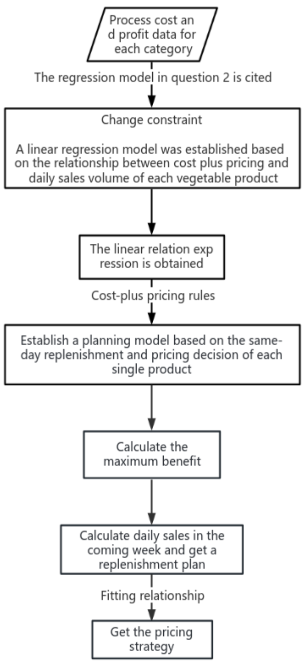

Figure 2 Flowchart

For each vegetable category's total daily replenishment and pricing strategy for the coming week, this paper shows the partial solution results for the total daily replenishment and maximum revenue for the six categories in the coming week.

Using MATLAB, the total daily replenishment of aquatic root vegetables with maximum yield results were obtained as follows in Table 2:

Table 2 Total daily replenishment and maximum yield results for aquatic root vegetables

	2023-7-1		**2023-7-2**		**……**	**2023-7-7**	
	sales volume	margins	sales volume	margins	……	sales volume	margins
CATEGORY 1	16.6128	1153.2	16.7242	1051.8	……	16.8163	889.97
CATEGORY 2	330.85		279.352		……	215.684	
CATEGORY 3	185.589		165.351		……	125.533	
CATEGORY 4	11.1525		10.8987		……	11.9637	
CATEGORY 5	4.6864		4.6968		……	4.7341	
CATEGORY 6	27.041		30.084		……	28.934	

4. Conclusions

This paper investigates automated pricing of vegetable category items to help superstores develop replenishment and pricing strategies. The article builds a linear regression model to predict the daily replenishment and pricing strategy for the coming week by analysing the sales data of vegetable categories. Firstly, total sales, costs and margins were processed through historical data, and then a linear regression model was established for the relationship between cost-plus pricing and total sales for each vegetable category. The model fitted the relationship between total sales and cost-plus pricing for different vegetable categories using the least squares method.

In terms of model solution, the paper shows the linear regression results for the example of chilli vegetables, which confirms the linear relationship between total sales and cost-plus pricing. The fitted effect plot indicates that the model is feasible. Subsequently, in order to optimise the superstore revenue, the article developed a non-linear planning model to solve the total daily replenishment and the maximum revenue for the coming week via MATLAB. The partial solution results of total daily replenishment and maximum revenue for six vegetable categories were obtained. In particular, the model takes into account factors such as transport loss rate to formulate the optimal replenishment strategy, and then substitutes the total daily replenishment amount into the multivariate linear expression to calculate the corresponding pricing strategy.

Through linear regression and nonlinear programming methods, combined with historical sales data, the article establishes a set of effective models, which provide superstores with reference suggestions for vegetable replenishment volume and pricing strategies based on data analysis.

References

[1] Cai Jianhu,Cao Weizang,Zhou Qian et al. Research on VMI inventory decision-making model for assembly system under supplier output uncertainty environment [J/OL].China Management Science, 1-14[2023-11-08]

[2] Tianjin's "food basket" stable in autumn [N]. Tianjin Daily, 2023-08-24 (010).

[3] Zheng L.Research on dynamic bulk inventory replenishment problem of community group-buying retailers [D].Zhongnan University of Economics and Law, 2022.

[4] Lai ZK.Beijing Fengtai makes every effort to protect residents' "food basket"[N].Workers' Daily, 2022-04-26 (004).

[5] Wu YAN.Increasing replenishment frequency to ensure personnel input [N]. Shenzhen Special Zone News, 2022-03-15 (A03).

[6] Liang, Shuting.Research on the inventory strategy of community fresh food retail terminal where time and stock quantity jointly affect spoilage rate [D]. Beijing Jiaotong University, 2020.

[7] Qiao Yannan.Research on the optimisation scheme of Q supermarket outlet layout based on improved SLP [D]. Tianjin University of Finance and Economics, 2020.

[8] Epidemic now, supermarket fresh C position "leading the way", these fresh basic skills must be strengthened [J]. Corporate Observer, 2020, (03): 111-113.

[9] ZHANG Jingfang,XIANG Wanli.Application of dynamic buffer inventory model in inventory management of agricultural products [J].Logistics Technology, 2018, 37 (12): 83-88.

[10] HAN HAN GWANG.Research on inventory management programme of frozen products category in community vegetable direct shops in Urumqi [D]. Xinjiang Agricultural University, 2017.