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Regression Analysis and Optimization Design of Automatic Pricing Replenishment Decision for Vegetable Items

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Abstract: Automatic pricing and replenishment decision-making for vegetable goods, Firstly, using linear regression model to optimize the pricing strategy in the next seven days, secondly, constructing mathematical model to synthesize the pricing strategy that has been derived to formulate a more comprehensive sales strategy, Combined with the spsspro software to solve the solution to achieve the maximization of the interests of the superstore. This study aims to develop a reasonable pricing replenishment strategy for supermarkets. By optimizing pricing and replenishment strategies, supermarkets can improve sales efficiency and profit maximization, reduce costs and risks, and promote digital transformation and intelligent management.

Keywords: Vegetable Items; Optimization Model; Automatic Pricing And Replenishment Decision; Regression Analysis; Mathematical Model; Spspro

1. Introduction

In fresh supermarkets, vegetables have a short shelf life and their appearance tends to deteriorate as the selling time increases. Therefore, supermarkets replenish their stock daily based on historical sales and demand data to ensure the supply of each vegetable category for the day. With a wide variety of vegetables from different origins, merchants need to purchase goods between 3 to 4 in the morning, but they are not clear about the specific items and purchase prices. Prices generally use a "cost-plus pricing" method, and goods that are damaged during transportation or have deteriorated in quality are usually sold at a discount. From the demand side, there is a certain relationship between the sales volume of vegetables and time; from the supply side, from April to October there are more varieties of vegetables available, so supermarkets need a reasonable sales mix to adapt to the limited sales space.

Li Yali[1] took the characteristics of fresh products and inventory issues as the background, considering that the increase in product prices would lead to a decrease in demand, depicted a demand-related exponential function, and based on the classical economic order quantity inventory model, adopted a strategy of joint replenishment for multiple products to replenish, with the objective function of maximizing total profit, constructed a joint replenishment and pricing coordination decision-making model for fresh products. In terms of automatic replenishment, Li Chunxiao[4] started from the structural framework and subsystem analysis of the unmanned supermarket replenishment system, deduced the design principles and replenishment methods of the system, and designed a more reasonable and efficient replenishment system and equipment. Wang Hongfei[7] started from the operational issues of specialty supermarkets for fresh products, based on STP theory, 4C theory, service marketing theory, and professional division of labor theory, proposed targeted measures for the problems existing in the operation of specialty supermarkets for fresh products in Zhengzhou. This paper establishes pricing strategy prediction through a linear regression model, constructs a mathematical model to comprehensively derive a more comprehensive sales strategy to maximize profits.

2. Data Sources and Assumptions

The data comes from the 2023 Higher Education Press Cup National College Students Mathematical Modeling Competition, C topic. To facilitate problem-solving, the following assumptions are proposed: (1) Assume that the sales data is correct and complete, with no duplicate or erroneous records; (2) Assume that consumer demand for purchasing goods is cyclical; (3) The time of vegetable procurement will not affect the purchase demand of consumers on that day; (4) Assume that vegetables will only suffer losses according to the corresponding loss rate and will not be affected by natural disasters to cause massive losses.

3. Decision-Making for Automatic Pricing and Replenishment of Vegetable Products Based on Regression Models

3.1 Research Methods

Optimize the pricing strategy for the next seven days using the organized data. First, construct a regression model to obtain the linear relationship between total sales and cost-plus pricing, and then solve for the results using the formula model.

3.2 Regression Analysis

Conduct regression analysis on the data to obtain a linear regression equation between total sales and cost-plus pricing, which can be used for subsequent data processing and optimization. Figure 1 shows the fitting effect of the linear regression results.

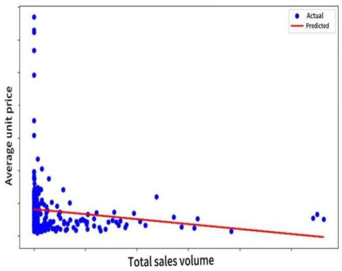

Figure 1. Linear Regression Fit Effect Chart

To prevent the situation where sales are zero but there is still a price from affecting the regression function, exclude cases where sales are zero during regression, resulting in the function: $y = -0.0003057x + 22.45$,among them R^2 is0.9358, $RMSE$ is3.556.

3.3 Construction of Mathematical Models

Calculate the total sales S_s and total profit SSF :

$$S_s = \sum n \cdot p_b \tag{1}$$

$$SSF = \sum n \cdot (b_s - b_p) \tag{2}$$

Where, n is the unit weight for the day, b_p is the wholesale price per item, and b_s is the selling price per item.

Cost-plus ratio calculation:

$$\alpha = \frac{S_s}{S_s - SF} - 1 \tag{3}$$

Among which, the profit is SF .

To maximize the profits of supermarkets, it is very important to balance production and sales, so the total daily replenishment is converted into total daily sales for prediction. The linear regression equation above is transformed into:

$$Y_{ij} = -0.0003057X_{ij} + 22.45 \tag{4}$$

Among them, $i = 1,2,3,...,7$ represents the dates of a week, and $j = 1,2,3,...,6$ represents the six major categories, which are cruciferous vegetables, leafy vegetables, solanaceous vegetables, pepper vegetables, edible fungi, and aquatic root vegetables.

For the future weekly replenishment total and pricing strategy of each vegetable category, this article will take solanaceous vegetables as an example for solving.

The decision variables are set as X_{iq} , $i = 1,2,3,...,7$, representing the total sales volume of solanaceous vegetables on the ith day; the pricing adopts a cost-plus pricing method, with the daily profit set as f_{iq} ; therefore, the final pricing Y_{iq} can be represented as:

$$Y_{iq} = (1 + f_{iq})P_{iq} \tag{5}$$

Wherein, P_{iq} represents the purchase cost of the eggplant category on that day.

Therefore, the profit for this category on day i is:

$$W_{iq} = f_{iq} \cdot X_{iq} \tag{6}$$

The total profit of supermarkets within seven days is:

$$W = \sum_{i=1}^{7} \sum_{j=1}^{6} W_{ij} \tag{7}$$

Among them, $i = 1,2,3,...,7$; $j = 1,2,3,...,6$.

Therefore, the model is:

$$s.t.\begin{cases} y_{ij} = -0.0003057x_{ij} + 22.45 \\ y_{ij} = (1 + f_{ij})P_{ij} \\ W_{ij} = f_{ij} \cdot X_{ij} \\ W = \sum_{i=1}^{7}\sum_{j=1}^{6} W_{ij} \\ x_{ij}, y_{ij}, W_{ij} > 0 \\ f_{ij} \in R \\ i = 1,2,3,...,7 \\ j = 1,2,3,...,6 \end{cases} \tag{8}$$

The sales volume of nightshade vegetables for the next seven days can be calculated using the above formula, which also determines the daily

replenishment quantity.
Then apply spsspro to perform regression fitting model and obtain pricing strategies for the next seven days.

Table 1. Results of Daily Replenishment Quantity for Solanaceae1

Date	2023/7/1	2023/7/2	2023/7/3	2023/7/4	2023/7/5	2023/7/6	2023/7/7
Daily replenishment total / kilo	9.791	8.732	5.622	10.835	3.295	6.624	6.153

Table 2. Pricing Strategy for Solanaceae2

Date	2023/7/1	2023/7/2	2023/7/3	2023/7/4	2023/7/5	2023/7/6	2023/7/7
Pricing strategy	0.573781	0.573377	0.576475	0.572993	0.571804	0.571689	0.571456

4. Optimization of the Automatic Pricing and Replenishment Decision Model

4.1 Research Ideas

On the basis of the established model, add four additional constraints. Through the analysis of the comprehensive loss rate, classify the products by their shelf life, which in turn better informs sales decision-making. Optimize the above mathematical model for a solution that yields the results maximizing the supermarket's profits.

4.2 Data Preprocessing

4.2.1 Propose constraints
Constraint 1: The order quantity for each item must meet the minimum display quantity of 2.5 kilograms. Constraint 2: The total number of items sold must be controlled between 27 and 33. Constraint 3: The order quantity and pricing strategy for each item must satisfy the market supply and demand relationship for each category of vegetable products. Constraint 4: Consider spoilage conditions and adjust the shelf life accordingly.
4.2.2 Draw histograms
Calculate the average unit price and average sales volume for 247 items, resulting in the outcomes shown in Figures 2 and 3.

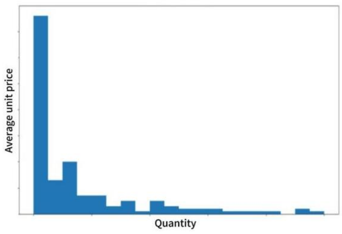

Figure 2. Histogram of Average Unit Prices

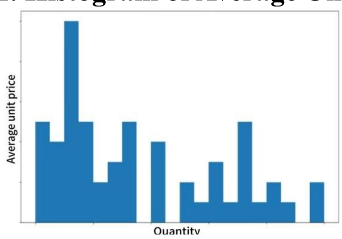

Figure 3. Histogram of Average Sales Volume

4.2.3 Analyzing Loss Rate
Due to the short shelf life of vegetables, most single items, if not sold immediately on the day of arrival, may not be able to be sold the next day. Therefore, loss rate data is introduced to correct the shelf life of single items, establishing a correlation between loss rate and shelf life, and further filtering out single items that do not meet the requirements.
According to the loss rate, single items are roughly divided into three categories: low, medium, and high protection. The following divisions are based on: High protection: loss rate ≤ 6.07%; Medium protection: 6.07% < loss rate ≤ 14.43%; Low protection: loss rate > 14.43%.
For these single items, the length of their shelf life is determined based on the size of their loss rate, for example, in the formulation of replenishment plans and display adjustments. Vegetables in the long shelf life category require fewer replenishments compared to medium and short shelf life categories, to prevent overstocking, as they have a longer shelf life. On the other hand, the short shelf life category may require more frequent replenishments to ensure there is enough fresh vegetables on the shelves.
3.3 Optimization Model and Solution
Introduce a switch variable q_i = 0 or 1, $i=1,2,3,...,247$ .A value of 1 indicates that the item was sold on that day, and a value of 0 indicates that the item was not sold on that day.

$$q_i = \begin{cases} 0, \text{The ith item was not sold on that day} \\ 1, \text{The ith item was sold on the same day} \end{cases} \quad (9)$$

That is:
Represent the constraint condition 2 using q_i :

$$27 \le \sum_{i=1}^{247} q_i \le 33 \quad (10)$$

For constraint condition 1:
The total amount of each individual item a_i , $i=1,2,3,...,247$ must be greater than 2.5kg, that is:

$$a_i \ge 2.5, i=1,2,3,...,247 \quad (11)$$

The calculation of profit is done using the method of the original model. Let the profit margin of a single item be denoted as a_i , then:

$$y_i = (1 + f_i)P_i \tag{12}$$

Where, y_i is the pricing for the single item of type i , P_i is the cost of the single item in type i .

Total profit is represented as:

$$W = \sum_{i=1}^{247} f_i x_i \tag{13}$$

In summary, the model optimization is as follows:

$$s.t.\begin{cases} y_i = -0.0003057\, x_i + 22.45 \\ y_i = (1 + f_i)P_i \\ 27 \le \sum_{i=1}^{247} q_i \le 33 \\ W = \sum_{i=1}^{247} f_i x_i \\ q_i = 0 \; or \; 1 \\ a_i \ge 2.5 \\ f_i, y_i \in R \\ P_i, x_i \ge 0 \\ i = 1,2,3,...,247 \end{cases} \tag{14}$$

The result can be seen in Table 3.Ultimately, we concluded that the profit was 1055.41, having sold 32 different products, which maximized the revenue.

5. Formulate Pricing and Replenishment Decision Recommendations

To better formulate restocking and pricing decisions for vegetable products, it is necessary to collect additional data beyond sales and wholesale data. This includes data on customer traffic, weather and holiday information, and seasonal demand levels.

Specific suggestions are as follows:

(1) Understand the customer traffic for each day or time period. Different times and dates may have varying levels of customer traffic, which is directly related to vegetable sales volume. Knowing peak and off-peak times can help businesses adjust display strategies, promotion schedules, and inventory levels.

(2) Gather future weather forecasts and holiday data. Weather conditions, such as heavy rain or heatwaves, can affect consumer shopping behavior. By obtaining accurate weather forecast information, supermarkets can arrange their inventory reasonably and reduce losses from vegetables spoiling or deteriorating due to weather.

Holidays usually come with specific consumer habits and promotional activities. Typically, on weekends and public holidays, people have more free time to shop, and supermarkets see higher customer traffic.

(3) Collect data on the demand, sales volume, and prices of various vegetables in different seasons. Certain vegetables may be more popular in certain seasons. Understanding these seasonal changes can help businesses adjust their restocking strategies. Seasonal variations directly impact consumer demand and purchasing behavior for vegetables.

Table 3. Solution Results

name	Sweet potato leaves	China Waxgourd	Cabbage	Amaranth	Yunnan lettuce/pack	baby cabbage	Yunnan Amaranth /pack	Zou Pi Pepper/piece
Replenishment	5.96	7.56	6.07	5.32	14.96	16.29	9.24	5.40
Profit	13.96	14.81	11.83	9.57	26.62	28.83	15.89	8.96
name	Spinach	Yunnan lettuce	Sweet cabbage	Pakchoi	Celtuce	Napa cabbage(2)	Yunnan lettuce	Chinese cabbage(1)
Replenishment	6.557	18.524	3.543	8.462	5.210	9.453	11.245	4.025
Profit	24.294	58.184	11.019	25.8514	14.9110	26.6764	30.4402	9.7808
name	Broccoli	Lotus root(1)	Eggplant	Purple Eggplant(2)	Green eggplant(1)	Red bell pepper(1)	Spicy chili pepper	Bird's eye chili(portion)
Replenishment	18.124	21.543	3.224	17.245	4.238	5.872	11.537	15.246
Profit	59.319	49.463	13.2345	50.873	10.42	37.64	4.1729	38.450
name	Wuhu green pepper (1)	Screw chili (portion)	Xixia Flower Mushroom(1)	Pleurotus eryngii(1)	Enoki mushroom(1)	White Jade Mushroom (bag)	Button mushroom	Enoki mushrooms (package)
Replenishment	54.270	10.523	3.240	4.216	8.253	4.102	8.247	30.240
Profit	118.3086	22.571	24.180	17.336	27.086	11.088	15.33	40.522

6. Concluding Remark

This article combines various methods to conduct a quantitative analysis of fresh supermarkets, constructs models, and analyzes the pricing strategy of the entire supermarket. By using regression models, it helps establish the relationship between total sales and cost-plus pricing, predicting the pricing of vegetables within a week. To incorporate practical constraints, the proposed model is optimized. It predicts the replenishment strategy more precisely to maximize profits. Proposals include finding customer flow data, weather and holiday data, and seasonal demand data. This is beneficial for supermarkets to better operate and maximize profits. It has significant reference value for other fresh supermarkets to implement automatic pricing and replenishment decisions in combination with specific data.

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