

Research on an optimization scheme for automated pricing and replenishment decisions for vegetable commodities

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Abstract. With the increasing competition in the fresh food market and the emergence of fresh food superstores, a reasonable pricing strategy has become crucial to the operation of superstores. This paper focuses on the relationship between sales volume and pricing as well as the impact of total replenishment and pricing strategy on vegetable sales. By analysing the sales data of the chilli category, a certain positive correlation between sales volume and pricing was found, which was quantitatively analysed using a polynomial regression model. The total replenishment and pricing strategy was analysed using the chilli category as an example, and a cost-plus pricing strategy was used to optimise the total replenishment and pricing, resulting in the total replenishment and pricing strategy for the week ahead. A linear regression model was developed and optimally solved using a simulated annealing algorithm to obtain the daily replenishment quantity and pricing strategy for each vegetable, considering the replenishment category and minimum weight constraints. Ultimately, the optimal replenishment quantity and pricing strategy for each vegetable item were obtained, providing a reference basis for vegetable sales.

Keywords: Polynomial Regression, Simulated Annealing algorithm, vegetable marketing.

1. Introduction

As the consumption level of China's residents continues to rise, the traditional farmers' market has gradually failed to adapt to the higher needs of the people's life, so the fresh food supermarkets came into being. Fresh produce supermarkets are specialized in the operation of agricultural and sideline products consumed in people's daily life and combined with the modern supermarket business philosophy of professional stores, chain stores, and its business philosophy is in line with the requirements of the further deepening of the food basket project that began in the early 1990s. Fresh super refers to specialize in people's daily life consumption of agricultural and sideline products and the combination of modern supermarket business philosophy of professional stores, chain stores, its business philosophy in line with the early 1990s began the food basket project to further deepen the requirements. If the products purchased by fresh food superstores are not sold on the same day, they cannot be sold again on the following day. Therefore, supermarkets usually use the historical sales and demand of each product as a reference for daily replenishment [1] [2].

To give a rational pricing and replenishment strategy for vegetable sales, we analyzed the existing literature on the subject. Generally, many recent studies have reported that the unstable demand for fresh agricultural products leads to the problem of shortage or surplus in supermarket chains, which easily leads to the inability of merchants to make a good strategy for the purchase and replenishment of fresh products. At the same time, price is the basic competitive means of supermarket chains, reasonable inventory and pricing strategy for the operation of supermarkets has become critical [3].

Based on the preprocessed data, the relationship between pricing and sales of chili peppers is established by building a linear regression model for chili peppers and vegetables as an example, and the results of linear regression are obtained by using the MATLAB fitting tool. For the total amount of replenishment and pricing strategy, the cost plus pricing strategy is used to analyze and optimize the problem, taking the supermarket revenue as the objective function, constructing a linear programming model, solving for the total amount of daily replenishment as well as the corresponding

pricing strategy, and obtaining the total amount of replenishment and the pricing strategy that maximizes the revenue of the supermarket [4] [5] [6].

2. The basic funamental of Development of replenishment plans

2.1. Relationship between sales volume and pricing

There are six vegetable categories involved in this question. An example of chilli category is explained and analysed here. By analysing the data of sales and pricing of chilli category and plotting it to form a line graph as figure 1:

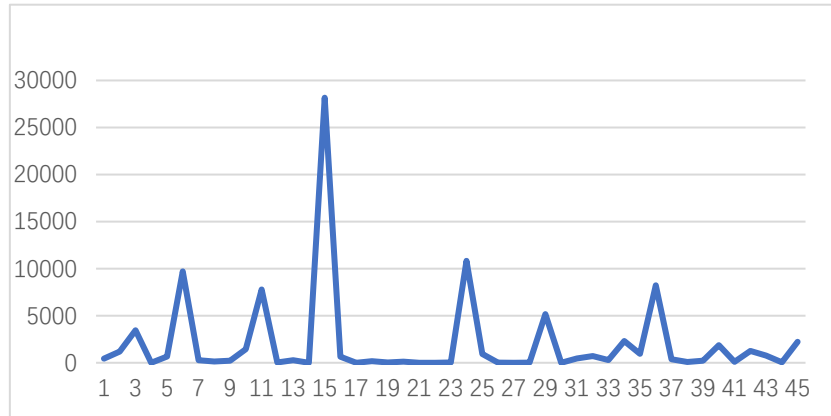


Figure 1. Total Sales Volume of Individual Products in the Chili Category

This post addresses the problem of automated pricing and replenishment decision optimisation schemes for vegetable items. Under the premise that the superstore considers doing replenishment planning on a category-by-category basis, a significant correlation is obtained between the total sales volume of each vegetable category and cost-plus pricing, and the total daily replenishment volume and pricing strategy that makes the superstore's revenue maximised are formulated. Afterwards, the condition of limited selling space for vegetable items is introduced to further develop the strategy, and then the profit amount is calculated. Through model optimisation, the replenishment quantity and pricing strategy for each item that maximises the profitability of the hypermarket are obtained. From the above figure we can roughly see that there is a certain positive correlation between the pricing and sales of the chilli category, and this relationship will be analysed quantitatively below. In this paper, polynomial regression model is used to describe the relationship between pricing and sales volume of chilli category [7]:

$$\begin{cases} y(x, \omega) = \omega_0 + \omega_1 x + \omega_2 x^2 + \omega_3 x^3 \\ E(\omega) = \frac{1}{2} \sum_{n=1}^N |y(x_n, \omega) - t_n|^2 \end{cases} \quad (1)$$

Where y represents the pricing of the chilli category, x represents the sales volume of the chilli category, ω_0 , ω_1 , ω_2 , ω_3 represent the constant term coefficients, the primary term coefficients, the secondary term coefficients, and the tertiary term coefficients, respectively, and ε represents the error.

2.2. Total replenishment and pricing strategy

For the total daily replenishment and pricing strategy for each vegetable category for the coming week we have also analysed the chilli category as an example.

A cost plus pricing strategy is used to analyse and optimise the problem, the most important of which is to combine the cost and the required profit together to determine the selling price. Therefore, there are:

$$y_i = (1 + \alpha_i) \vartheta_i$$

Where y_i represents the pricing of the chilli category on day i , α_i represents the interest rate on day i , and ϑ_i represents the cost of entry on day i .

This gives the profitability of the chilli category on day i as:

$$A_i = \alpha_i x_i (1 - \mu) \quad (2)$$

Where μ is the loss rate of chilli type.

Then the total profit for the coming week is:

$$A = i = 17j = 16(A_{ij}) \quad (3)$$

Where j from 1 to 6 denotes aquatic rhizomes, foliar, cauliflower, aubergine, chilli, edible mushrooms, respectively.

In summary, the linear programming model can be obtained as follows:

$$\max_{A_{ij}} A = \sum_{i=1}^7 \sum_{j=1}^6 (A_{ij}) \quad (4)$$

$$s. t. \begin{cases} y_{ij} = \beta_{j0} + \beta_{j1} x_{ij} \\ y_{ij} = (1 + \alpha_{ij}) \vartheta_{ij} \\ A_i = \alpha_i x_i (1 - \mu) \\ A_i = \sum_{j=1}^6 (A_{ij}) \\ x_{ij}, y_{ij}, A_i \geq 0 \\ \alpha_i \in R \\ i = 1, 2, \dots, 7 \\ j = 1, 2, \dots, 7 \end{cases} \quad (5)$$

Where $j = 1, 2, \dots, 7$ denotes aquatic roots and tubers, flowers and leaves, cauliflowers, aubergines, peppers, and edible mushrooms, respectively.

2.3. Replenishment and Pricing Strategies

The solution can be viewed as a predictive model for a small range of times and requires a linear regression model, based on the question the following constraints can be analysed:

For 251 vegetable items, first of all, each day to choose a different combination of vegetables, under the premise of the total number of items available for sale to control 27-33, need to introduce Boolean variable $b_i = 0$ or 1 and $i = 1, 2, \dots, 251$, the value of 1 means that the vegetable items were sold on that day, and the value of 0 means that for that day there was no sale, so we can get the following equation:

$$27 \leq \sum_{i=1}^{251} b_i \leq 33 \quad (6)$$

For each vegetable item ordered, it is necessary to satisfy their minimum display quantity, even if their order quantity is greater than 2.5 kg, let the total quantity of each item be s_i , which can be expressed as

$$s_i > 2.5 \quad (7)$$

For the calculation of profit, still using the understanding of cost-plus pricing in section 5.3.1, w_i is set to be the profit margin, d_i is the pricing of the i th individual item, and r_i is the cost price of the i th individual item. Thus, the pricing of each individual item can be expressed as

$$d_i = (1 + w_i) r_i \quad (8)$$

The final total profit is expressed as

$$W = \sum_{i=1}^{251} w_i x_i \quad (9)$$

In summary, the replenishment and pricing strategies optimisation model is as follows:

max

$$W = \sum_{i=1}^{251} b_i w_i x_i \quad (10)$$

$$s. t. \begin{cases} 27 \leq \sum_{i=1}^{251} b_i \leq 33 \\ s_i > 2.5 \\ d_i = (1 + w_i)r \\ r_i, x_i \geq 0 \\ b_i = 1 \text{ or } 0 \\ i = 1, 2, 3 \dots 251 \end{cases}$$

For direct solution of the established planning model, solving it using Matlab requires a huge amount of computation and consumes a lot of time. Therefore, the simulated annealing algorithm is used to optimise the solution of the established multivariate planning model.

The idea of the simulated annealing algorithm was first proposed by *Metropolis* et al. Its starting point is based on the similarity between the annealing process of solid substances in physics and general combinatorial optimisation problems. Meanwhile, the simulated annealing algorithm is a general optimisation algorithm, which is a non-cluster optimisation type of algorithm, does not need to set initial values and is easy to use. Based on the establishment of multiple linear regression equations, the optimal solution is found by combining its optimisation [8] [9].

First initialise the initial solution x and the initial temperature T . When the temperature T is greater than the termination temperature Tf , the following loop is executed:

(1) To generate a new solution x' , the difference of the calculated objective function can be obtained by transforming the current solution and random disturbance as follows:

$$\Delta E = f(x') - f(x) \quad (11)$$

If ΔE is less than or equal to 0, accept the new solution x' . If ΔE is greater than 0, the new solution x' is accepted with a certain probability, and the probability is calculated as follows:

$$\exp(-\Delta E/T) \quad (12)$$

(2) Update the current solution x to x' , after which the temperature T can be reduced by linear cooling or exponential cooling.

(3) Return the current solution x , as the optimal solution.

Where $f(x)$ represents the objective function, ΔE is the difference between objective functions, T is the current temperature, and Tf is the termination temperature. The specific idea of the algorithm is as Figure 2 follows:

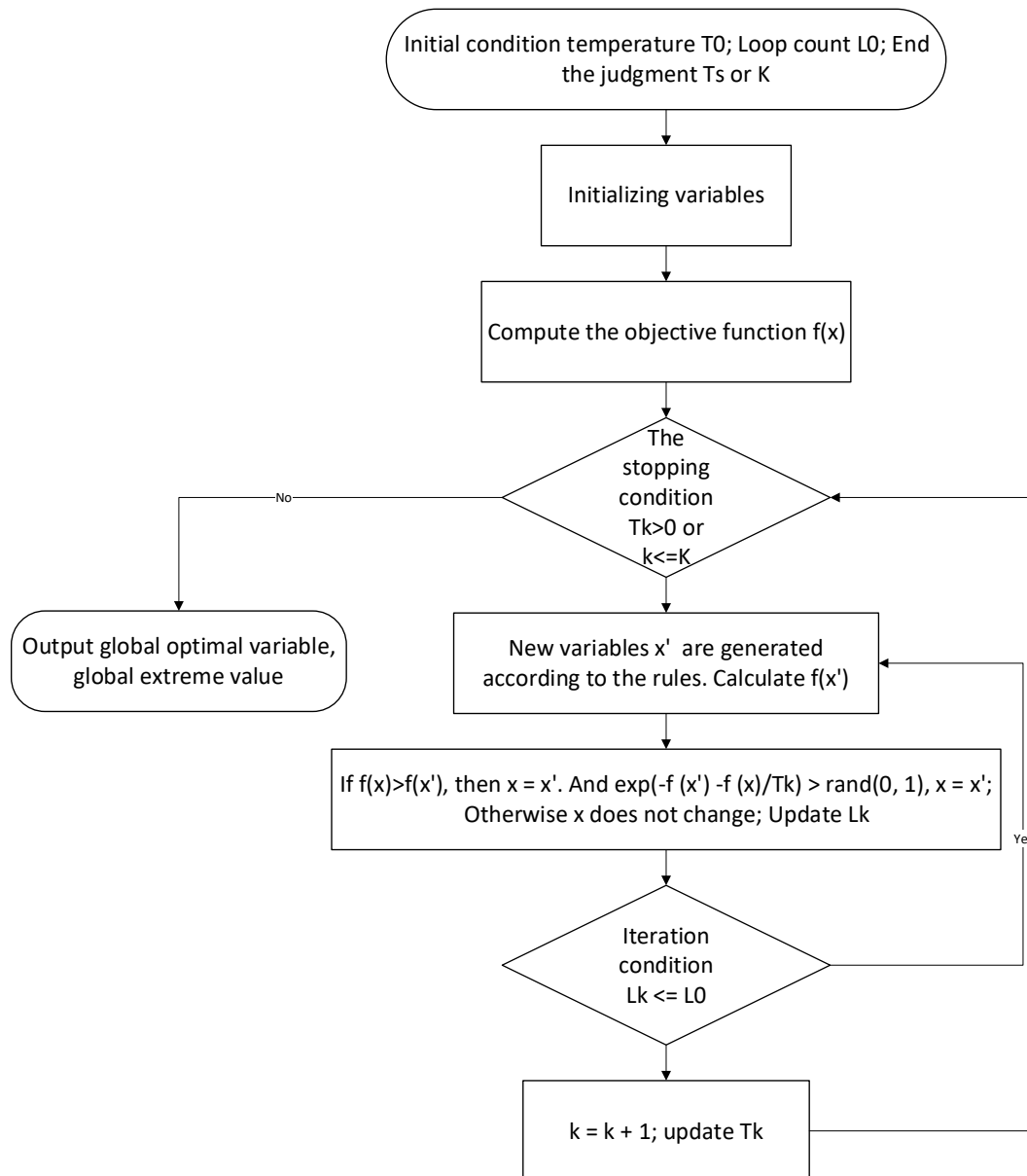


Figure 2. Simulated annealing algorithm flow chart

3. Results

3.1. The establishment of automated pricing and replenishment strategies for vegetables model

The replenishment strategy developed to maximise the revenue of the superstore is implemented by MATLAB software [10]. This data comes from the website <http://www.mcm.edu.cn/>.

3.2. Analysis of experimental results

There is a significant correlation between its sales volume and pricing, which satisfies the basic assumptions about its relationship, and the following results are obtained after solving using MATLAB:

$$y = 9.508 + 0.268x + 0.150x^2 - 3.623x^3 \quad (13)$$

Based on superstores doing replenishment plans on a category basis, after calculations the results are obtained as table 1:

Table 1. Total daily replenishment and pricing strategy for the chilli category

Dates	chilli category	
	Total daily replenishment (kg)	Pricing strategy (%)
2023-07-01	55.144	55.14%
2023-07-02	103.235	103.235%
2023-07-03	98.564	98.564%
2023-07-04	63.187	63.187%
2023-07-05	103.635	103.635%
2023-07-06	95.648	95.648%
2023-07-07	64.985	64.985%

With limited room to sell vegetable items, superstores want to further develop replenishment plans for individual items, the final results were obtained as shown in the Table 2 below:

Table 2. The result of replenishment and pricing strategies

product	daily replenishment (kg)	pricing strategy	product	daily replenishment (kg)	pricing strategy
Baby Bok Choy	3.271	117.19%	Red Pepper (2)	2.672	101.98%
Yunnan Lettuce	10.434	132.43%	Crabmeat Mushroom & White Jade Mushroom Duo (Box)	1	87.53%
Chrysanthemum Coronarium	9.104	124.32%	Honghu Lotus Root (Powdered Lotus Root)	6	74.11%
Beefsteak Oilseed Rape	18.125	92.4%	Little Bok Choy (1)	5.231	122.7%
Purple Eggplant (2)	2.929	42.61%	Yunnan Lettuce (Portion)	14	97.84%
Xixia Shiitake Mushroom (1)	18.27	46.47%	Yunnan Oilseed Rape (Portion)	10	93.41%
Broccoli	18.137	61.02%	Spinach (Portions)	15	133.71%
Net Lotus Root (1)	27.29	126.38%	Fishbulb (Portions)	1	64.42%
Zijiang Beetroot	2.219	57.59%	Peppers (Portions)	18	119.58%
White Mushroom (Bag)	2.5	127.25%	Icweed (Box)	12	111.88%
Wuhu Green Pepper (1)	27.101	59.48%	Black Porcini Mushrooms	22	73.15%
Apricot Mushroom (2)	3.115	138.28%	Round Eggplant (2)	7.579	37.88%
Cabbage (Portion)	12	74.9%	Cabbage	5.968	31.36%
Agaricus Bisporus (Box)	10	52.00%	Golden Needle Mushroom (Box)	7.564	95.36%
Green & Red Pepper Combo (Servings)	6	57.39%			

4. Conclusion

This post addresses the problem of automated pricing and replenishment decision optimisation schemes for vegetable items. Under the premise that the superstore considers doing replenishment planning on a category-by-category basis, a significant correlation is obtained between the total sales volume of each vegetable category and cost-plus pricing, and the total daily replenishment volume and pricing strategy that makes the superstore's revenue maximised are formulated. Afterwards, the condition of limited selling space for vegetable items is introduced to further develop the strategy, and then the profit amount is calculated. Through model optimisation, the replenishment quantity and pricing strategy for each item that maximises the profitability of the hypermarket are obtained. There may be limitations such as data processing bias in the research process, and it is hoped that subsequent studies could be done.

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