Optimization Study on Replenishment and Pricing Strategies for Vegetable Commodities

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Abstract. In the face of diverse consumer demand and fierce market competition, it is crucial to optimize replenishment and pricing strategies for perishable vegetables, aiming at scientific and efficient management to maximize revenue. This article visualized and analyzed recent sales data with incoming prices and wastage rates. A time series model was utilized to predict sales trends and develop a purchasing plan. Considering the transportation loss, we choose to sell at a discount. For the treatment of selling price, we use the selling price of the last three years as the initial selling price, and then optimize the up and down fluctuation of the selling price by using single-objective nonlinear programming and differential evolution method to maximize the profit. These strategies help to meet customer needs, enhance satisfaction and loyalty, optimize cost control and supply chain management, enhance market competitiveness, flexibly respond to market fluctuations, and reduce operational risks. An in-depth study of these strategies is crucial for the sustainable development of supermarkets.

Keywords: Iterative algorithm, differential evolutionary algorithm, single-objective nonlinear programming, time series models.

1. Introduction

In the current retail industry, the optimization of vegetable merchandise replenishment and pricing strategies is a key factor in ensuring competitiveness and improving the profitability of supermarkets. With the increasing diversity of consumer demands and intensifying market competition, retailers need to adopt more scientific and efficient methods to manage the replenishment and pricing of their commodities. Especially for perishable vegetable commodities, how to optimize replenishment and pricing strategies to maximize revenue while ensuring that market demand is met has become an important research topic in retail management [1] [2].

In this study, the time series model, single objective nonlinear programming model, and differential evolutionary optimization algorithm are used to investigate the replenishment volume and pricing strategy. Time series models are a class of models used for modeling regression problems, where the entire modeling process is characterized only by time, and thus can be used for superstore sales forecasting. Objective nonlinear programming studies the extreme value problem of an n-element real function under the constraints of a set of equations or inequalities, and has been in the fields of economics, management, engineering, scientific research, and military, and has been widely used [3]. Superstore profit is the main objective and also conforms to the single-objective model, so it is feasible to use this model for this research [4]. Differential Evolutionary Algorithm is a heuristic stochastic search algorithm based on group differences, proposed by R. Storn and K. Price for solving Chebyshev polynomials [5]. This algorithm belongs to intelligent optimization algorithms, similar to heuristic algorithms such as ABC and PSO, which are effective tools used to solve optimization problems, and has been widely used in process optimization, power allocation, optimization of mechanical design parameters, robotic motion planning, information extraction in signal processing, modeling of biological systems, decision making problems, system parameter identification and fault diagnosis, and training of neural networks [6] [7]. Since the differential evolutionary algorithm is an efficient global optimization algorithm, it is feasible to be used to explore optimization class problems such as superstore replenishment and pricing strategies [8].

To study the optimization of replenishment and pricing strategies for vegetable commodities, we first intuitively display the data characteristics of each vegetable in bar charts, followed by single-objective nonlinear programming to ensure that the superstore revenue is maximized, and at the same time, we use iterative and differential evolutionary methods to fluctuate the selling price of the vegetables, respectively, to achieve the optimal selling price combinations that maximize the total profit.

2. Constructing an Optimization Model

2.1. Processing of data

The data in this paper comes from http://www.mcm.edu.cn/, through the data provided by the official website we screened the types and sales of vegetables available for sale in the week from June 24, 2023 to June 30, 2023. Through the sales of vegetables this week, we use the time series model to predict the sales of all kinds of vegetables on July 1, 2023, because there is only one week, the time is relatively short, and there is no normal distribution of the sales of vegetables in a cycle, so we can directly carry out the time series prediction, and the prediction results are shown in Figure 1:

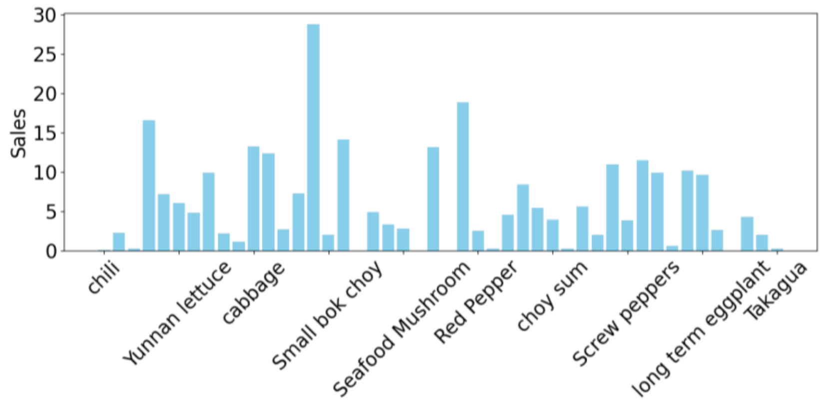

Figure 1. Projected sales of saleable vegetables (kg)

From the above forecast results, we can see that 46 categories of vegetables can be sold on July 1, 2023, with the most sold being Millet Peppers, followed by Purple Eggplants and Oatmeal Vegetables, and the lesser sold being Chili Peppers, Mullein Peppers, and Green Thread Peppers. Most of the rest had moderate sales.

Next, we deal with the input prices of these vegetables, the official website provided us with the input prices of all types of vegetables on July 1, 2023, we combine the above predicted saleable vegetables to visualize the input prices of these saleable vegetables, as shown in Figure 2:

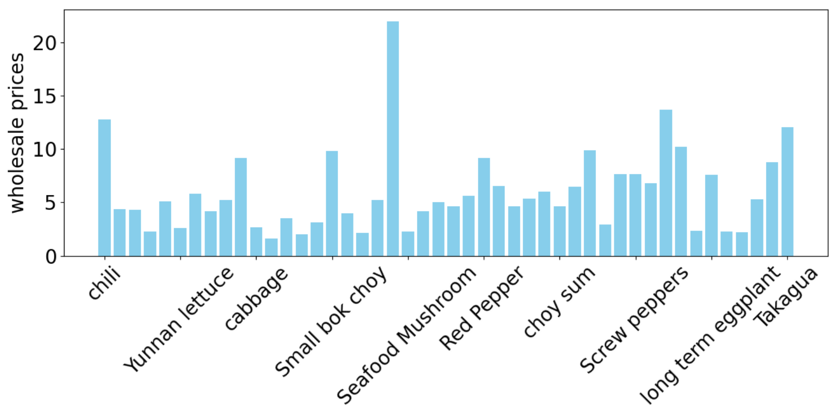

Figure 2. Bar chart of input price of marketable vegetables (kg/yuan)

From the above figure, we further understand that most of the vegetables are priced at 10 yuan per kilogram, with the most expensive being the Honghu Lotus Root Strap, which reaches 22 yuan per kilogram. At the same time, the superstore in the transportation of vegetables may lead to damage to the vegetables, the same, according to the accessories provided respectively corresponding to the saleable goods, the results are shown in Figure 3.

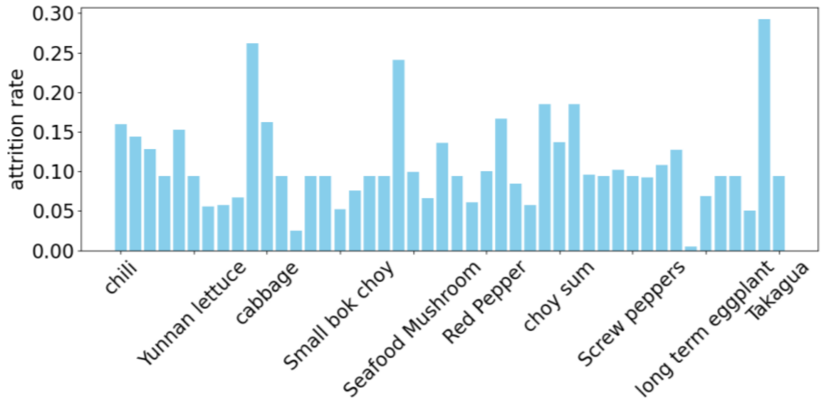

Figure 3. Wear and tear rate of saleable goods

2.2. Single-objective optimization model building and selection of optimization algorithm

In summary, we construct a single-objective nonlinear optimization model:
objective function:

$$\mathrm{Max}\ \ \alpha = \sum_{i=1}^{i=46} \mathrm{P_i} \times \mathrm{X_i}(1-\tfrac{1}{2}\mathrm{D_i})-\mathrm{W_i}\times\mathrm{X_i} \tag{1}$$

Where X_i represents the sales volume of the ith item (kilograms), P_i represents the sales price of the ith item (yuan), D_i represents the wastage rate of the ith item, W_i represents the purchase price of the ith item (yuan), and α denotes the total revenue of the superstore (yuan).

The rough flowchart is shown in Figure 4 below:

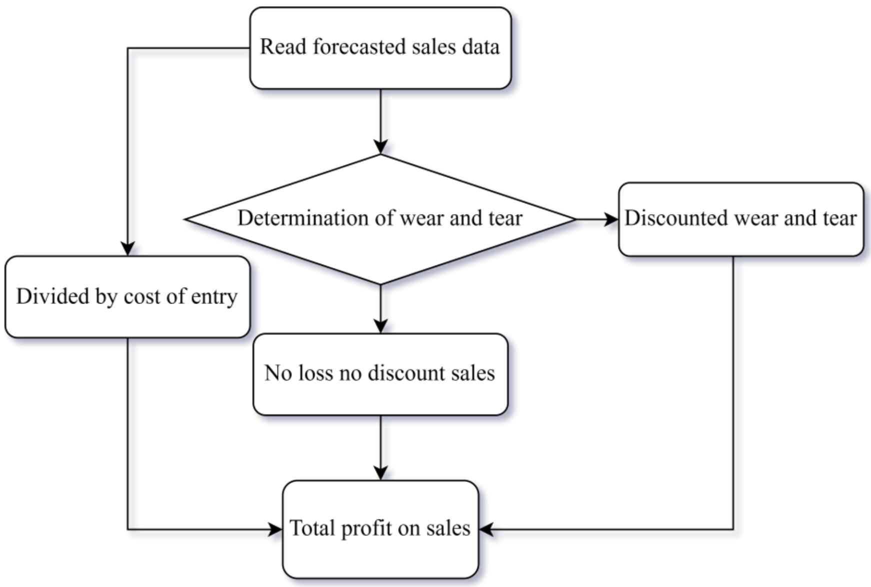

Figure 4. Single-objective planning model flowchart

For the loss of part of the discount sale of the strength of the selection, fresh supermarkets, the general freshness of vegetable commodities are relatively short, and the quality of time will become poorer and poorer, most of the varieties, if the day is not sold, the next day can not be sold, so that the super has also brought a certain degree of loss, taking into account the reduction of losses at the same time can reduce the warehouse inventory, decided to play 50% off sales. For the selection of commodity selling price, we take the average selling price strategy, that is, the initial price of various types of vegetables available for sale in the supermarket is the average selling price of the vegetables in three years, and then we choose the iterative method and differential evolution method to iterate up and down fluctuations in the initial price to find the best selling price combination to maximize the total profit [11].

An iterative method is a process of approximating a solution through a series of steps. It usually starts from an initial solution and then gradually adjusts the parameters of the solution according to some strategy until some convergence condition is satisfied or a predetermined number of iterations is reached. The iterative method is relatively simple to implement, but it tends to rely on the choice of initial conditions and tuning strategies and may be prone to fall into local optimal solutions [10].

The differential evolution method is a global optimization algorithm, the idea comes from the genetic algorithm, which is based on the differences between individuals in the population to produce new individuals. The algorithm forms new individuals by randomly selecting individuals in the population and using the difference vectors between the individuals as a new search direction. In the variation operation, the differential evolution algorithm generates variation vectors by randomly selecting individuals from the population and using the vectorial differences between these individuals as the search direction. Then, these variation vectors will exchange information with the parent individuals to generate trial vectors. By comparing the trial vectors with the fitness values of the parent individuals, the better individuals are selected to enter the next generation.

Differential evolutionary algorithms show high efficiency and global search ability in solving optimization problems, especially effective in dealing with high dimensional and complex optimization problems. However, it may need to face high computational complexity when dealing with large amounts of data.Iterative methods are usually simpler and easier to understand than differential evolutionary algorithms. However, iterative methods may take longer to converge to a solution and may not be as effective as differential evolutionary algorithms when dealing with complex problems. In addition, iterative methods have lengthy data and may not be suitable for handling large-scale datasets [12].

3. Results and discussions

3.1. Strategies for Vegetable Replenishment and Pricing

We bring the average selling price into the iterative method yielding the results shown in Figure 5 below:

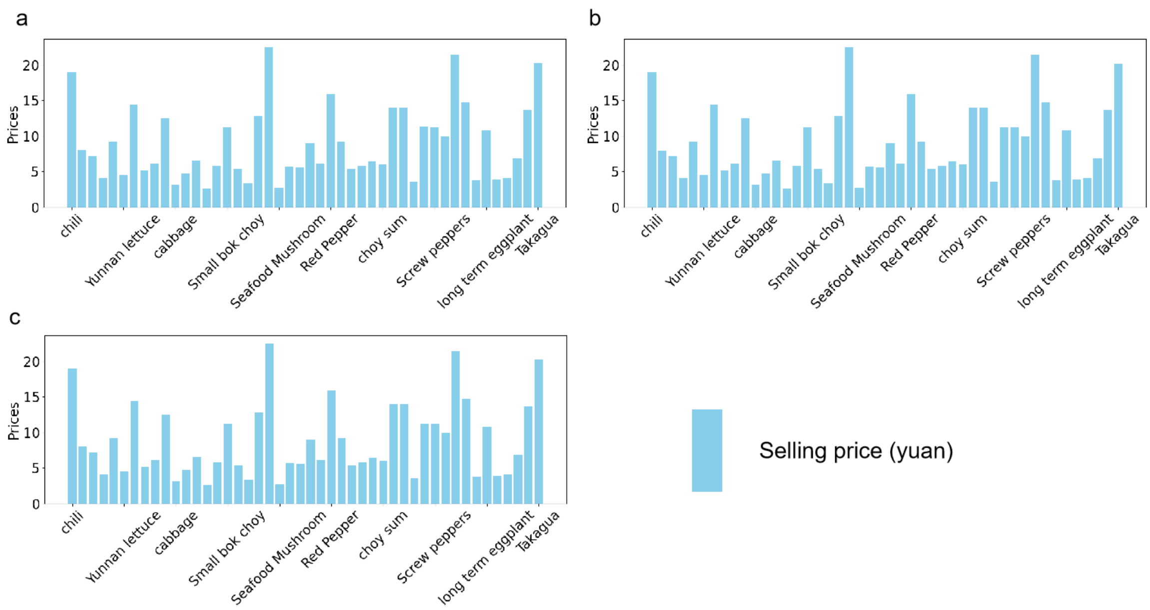

Figure 5. Iterative graph of vegetable selling prices. a: 1000 iterations; b: 10000 iterations; c: 100000 iterations

The results we obtained by importing each parameter of the saleable goods into the differential evolutionary algorithm are shown in Figure 6:

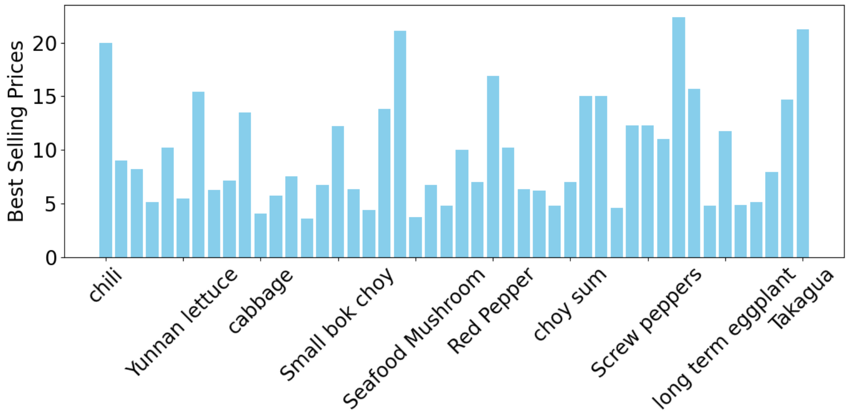

Figure 6. Selling prices under the differential evolution method

From Figure 5, we can see that in the process of these three iterations, the price change of the single product sold is very small and falls into the local optimum, so we choose the differential evolution hair for analysis. We select the first ten vegetables in the table to show, as shown in Table 1:

Table 1. Marketing parameters of selected vegetables

Product	Sales	Attrition Rate	Wholesale Prices	Selling Prices	Best Selling Prices
chili	0.03	0.1598	12.8	18.98	19.98
Shanghai Youth	2.24	0.1443	4.35	8	9
Yunnan rape	0.25	0.1281	4.33	7.2	8.2
Seafood Mushroom	2.78	0.0989	2.26	2.74	3.74
Takagua	0.27	0.0943	12.09	20.23	21.23
Yunnan lettuce	6.01	0.0943	2.6	4.46	5.46
net lotus root	4.78	0.0554	5.79	14.4	15.4
Agaricus bisporus	9.90	0.0576	4.17	5.46	6.23
Round Eggplant	2.20	0.0671	5.2	6.13	7.13
FieldChrysanthemum	1.10	0.2616	9.15	12.51	13.51

In this case, the higher selling prices were for Honghu lotus root strips, high melon, and Xixia mushrooms at 21.09 yuan per kg, 21.23 yuan per kg, and 22.4 yuan per kg, respectively, while the lower selling prices were for Cordyceps flowers and seafood mushrooms at 4.61 yuan per kg and 3.74 yuan per kg, respectively. Meanwhile, as can be seen from the table, the initial selling prices we selected are all slightly lower than the optimal selling prices, reflecting the fact that the historical selling prices of vegetables only provide a reference for the vegetable sales market in the future variable situation. With this sales ratio, the maximum return for the superstore is $747.04. To continue to increase the maximum return for the superstore, the following relevant data would need to be collected:

Consumer characteristics, weather, seasons, holidays, commodity mix, and market economic factors all have a profound impact on vegetable sales. From consumer age and gender to daily weather changes to seasonal sales trends, these factors combine to shape the vegetable market landscape. At the same time, holiday effects and consumer purchasing mix provide important references for promotional strategies. Finally, market economic trends are directly related to the replenishment and pricing of commodities. Taking all these factors into account, we can more accurately grasp market dynamics and provide effective business advice to merchants.

About consumer characteristics, we can explore the correlation between the vegetable varieties purchased by consumers according to their age, gender, height, weight physical condition, etc., and fine-tune the replenishment and pricing of various vegetable commodities by studying the distribution pattern of consumers in each characteristic.

For the weather factor, by recording the daily, weekly, and monthly weather and the corresponding sales of vegetable commodities in each period, study the trend of its changes, and then adjust the replenishment and pricing of each commodity according to the weather changes.

For the seasonal factor, the sales volume and pricing of each vegetable variety in the same quarter of each year can be recorded, to realize the prediction of the replenishment volume and pricing of vegetable commodities in a certain quarter in the future, and to achieve the maximization of revenue.

For commodity combination factors, according to the different combinations of commodities that consumers buy each time, using commodity correlation analysis (shopping basket analysis), to explore the correlation rules among commodities, to make adjustments to the display location and display volume of commodities, and to compare the replenishment volume of commodities required before and after the adjustment, the sales volume and the revenue of the superstore, to make adjustments to the pricing strategy.

For market economic factors: according to the different market economic situations every year, explore the impact on the sales of each vegetable variety when the market economy is up or down, and then make predictions on the future market economic changes, and real-time adjustments to the replenishment and pricing strategy of each vegetable category.

4. Conclusion

In this study, the replenishment quantity and pricing strategy of vegetable commodities are deeply optimized to maximize the revenue of superstores by integrating single-objective nonlinear programming model, differential evolutionary optimization algorithm and iterative method. After considering multiple factors such as consumer characteristics, weather, seasons, festivals, merchandise mix and market economy, the study found that the integrated optimization strategy can significantly improve the profitability of vegetable sales. According to the time series prediction, on July 1, 2023, the superstore should increase the procurement volume of vegetables such as millet peppers, purple eggplants, and oil sunflowers, and appropriately reduce the procurement of vegetables such as seven-colored peppers, fungus, and green silk peppers, in order to avoid transportation loss and profit loss due to low sales volume. At the same time, the analysis shows that the loss rate of vegetables in the transportation process is high, and superstores should further reduce transportation losses. In addition, for vegetables with large sales volume, small price adjustments can bring higher profits, while dishes with small sales volume should not be easily adjusted to avoid further reducing sales. Combining these factors, supermarkets can more accurately develop replenishment and pricing strategies to maximize profitability.

This paper applies the differential evolution method, as a superior optimization algorithm, which shows extraordinary application potential in the field of vegetable sales. For the complexity and variability of vegetable sales, the differential evolution method is able to deeply excavate the intrinsic patterns and trends of sales data through its powerful global search capability. By analyzing multiple factors such as consumer characteristics, weather, seasons, festivals, product mix, and market economy, DEM can reveal the complex relationship between these factors and vegetable sales, provide powerful support for sales strategy development, and provide a comprehensive quantitative basis for decision makers.

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