Research On Replenishment Strategy Of Vegetable Commodities Based On Linear Programming And Multi-Objective Particle Swarm Optimisation Algorithm

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Abstract. Because vegetable commodities are characterised by shorter freshness periods and diminishing character, they need to be replenished and priced on a daily basis based on historical sales and demand. In order to determine the optimal order quantity and sales price of vegetable commodities, this paper uses the least squares method to establish a regression model to obtain the relationship between sales volume and cost-plus pricing equation and verify the fitting effect, and then the total sales volume of the category obtained from the regression model and the cost-plus pricing equation combined with the derivation of the profit, the establishment of the optimisation model, the solution to obtain the replenishment volume and pricing strategy that will maximise the profitability of the superstore in the coming week. Considering the restricted situation of commodity categories, this paper chooses 0-1 integer planning,and adopts the multi-objective particle swarm optimisation algorithm to solve the optimisation model, and then iteratively calculates to get the global optimal solution, so as to find out the daily replenishment quantity of a single product and pricing strategy which will make the supercommercial supermarket have the largest revenue on 1 July.

Keywords: Optimisation Model; Multi-Objective Particle Swarm Optimisation Algorithm; Vegetable Commodity Pricing.

1. Introductory

In supermarket operations, sales and replenishment decisions for vegetable commodities are critical. However, due to the characteristics of vegetable commodities, including short shelf life, variable quality and unstable supply, supermarkets need to make rational replenishment decisions in the face of various uncertainties. In addition, supermarkets need to develop appropriate pricing strategies to ensure sales performance. Therefore, market demand analysis, replenishment decisions and pricing strategies have become important tasks in supermarket operations.

To determine the optimal order quantity and selling price of vegetable commodities, many researchers have conducted extensive studies in this area. Fang and Jiang (2018)[1] pointed out that bundled sales of fresh produce can reduce the spoilage rate and investigated the pricing strategy of produce bundling. Zhang (2021)[2] based on the perishable nature of fresh produce, and combined the spoilage rate and inventory control model to design and optimise a multi-level inventory control model for fresh produce. He (2021) [3] used blockchain technology (bct) to analyse the relationship between pricing decisions and profits in global supply chains based on the consideration of mathematical models. Lu [4] analysed the consumers' concern about the quality and safety of fresh vegetables, and by comparing the research results and pricing methods of scholars at home and abroad, and combining with the data from the actual research on supermarkets, a new pricing method was put forward --value loss pricing method. Mao[5] discussed the status quo and development trend of china's vegetable industry, and analysed the supply chain, prediction and fluctuation factors of agricultural product prices. Qian[6] started from the core collaborative pricing strategy of supply chain integration, and used the two-layer planning model to make a decision analysis of collaborative pricing. Zhao[7] studied that agricultural insurance is an important tool to protect farmers' income and stabilise agricultural production, and the use of appropriate copula function can fit the joint

distribution of vegetable production and price. Sun[8] predicted the probability of farmers' insurance under different price changes and reasonably predicted the future loss to provide a risk reference basis for them. Xu[9] the problem of urban vegetable supply needs to be solved comprehensively by adopting a variety of measures from production, circulation, sales and other aspects. Zheng[10] based on the stakeholder theory, constructs the joint pricing model of stakeholders in china's vegetable market, and argues the actual pricing problems in the vegetable market through specific arithmetic.

However, while previous studies have contributed, there is room for improvement in some key areas. In order to more accurately forecast replenishment quantities and pricing strategies for vegetable commodities and to better respond to market changes, we need to further improve our research methodology. Firstly, in terms of data processing and modelling, past studies have often failed to meet the requirement of high accuracy to comprehensively and effectively reflect changes in market demand. Second, in terms of replenishment and pricing decisions, existing studies lack reliable data support to improve the reliability of decisions. Therefore, there is a need to adopt more accurate methods and comprehensive data to establish precise models of order quantities and selling prices of vegetable commodities, so as to optimise the operational efficiency and competitiveness of superstores.

This paper aims to address the above problems and provide an in-depth discussion of the relationship between market demand and superstore replenishment and pricing decisions by means of data processing, fitting analysis and regression forecasting, and to provide an effective decision-making solution. The study will utilize accurate methods and comprehensive data to develop precise models of order quantities and selling prices of vegetable commodities in order to optimise the operational efficiency and competitiveness of superstores.

In summary, past research has focused on market demand analysis, pricing strategies and replenishment decisions for vegetable commodities. However, existing studies are deficient in the accuracy requirements of data processing and model building, and lack reliable data support. The innovation of this study is to use more accurate methods and comprehensive data to build accurate models of order quantities and sales prices of vegetable commodities in order to improve the operational efficiency and competitiveness of superstores.

2. Modelling vegetable commodity replenishment and pricing strategies

2.1. Regression model building and optimisation

Considering that superstores do replenishment planning on a category basis, the collected data set is processed to obtain the corresponding data of sales volume and cost-plus pricing for six categories from 1 july 2020 to 31 june 2023, which are shown in the figure below. The descriptive statistics of sales volume and cost-plus pricing for each category were analysed by spss software as shown in the figure below.

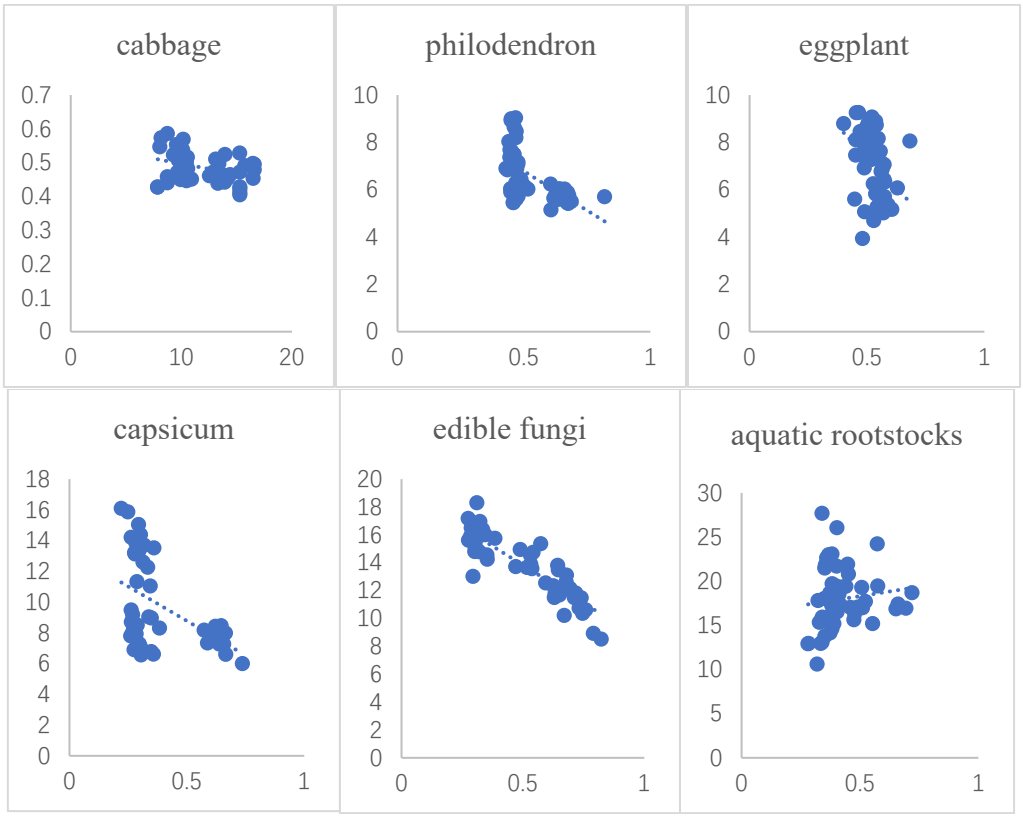

Figure 1. Category Single Product Correlation Chart

From the above graph, it can be seen that there is no significant linear correlation between sales volume and cost-plus pricing for each category and the distribution of the variables cannot be determined, so the spearman's correlation coefficient is solved for

$$\rho = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2\sum_{i=1}^{n}(y_i-\bar{y})^2}} \tag{1}$$

Solve to get the correlation coefficient.

Table 1. Table of category correlation coefficients

Foliage	Cauliflower	Aquatic Roots	Eggplant	Chilli	Mushrooms
0.185	0.136	-0.198	0.057	0.272	-0.09

From the correlation coefficients, it is observed that the linear correlation between total sales and cost-plus pricing for each category is low.

In order to avoid being too lengthy and cumbersome, this paper describes the six categories separately when describing total sales and cost-plus pricing. The following will be an in-depth study based on the sales data of edible mushroom category, which is known to have low linear correlation by the correlation coefficient, so the regression model is built using the least squares method.

$$\begin{cases} y_i = \beta_0 + \beta_1 x_i \\ \zeta \sim N(0, \sigma^2) \end{cases} \tag{2}$$

Where follows a normal distribution,1 is the coefficient of the independent variable, and 0 is the coefficient of the constant term.y_i denotes the pricing of edible mushrooms on day i, andx_i denotes the total sales volume of edible mushrooms on day i. The processed data were imported into SPSS software for least squares regression to obtain the results as shown in the table below.

Table 2. Regression test for edible mushrooms

Parameter	Value
F	F=174.291
Adjustment of R^2	0.776
R^2	0.781
standard error	0.446
t	43.268

Through the above table, it can be known that the overall regression coefficient is not 0, that is, there is a regression relationship between the variables, the analysis of the results of the f-test can be obtained.Equation for the model: Y = 19.278 - 10.898*x

The effect of fitting the true values to the predicted values is plotted using spspro as follows.



Figure 2. Regression fitting effect

Since the cost-plus pricing method that combines costs with the required profit to determine the final selling price is used, let the daily profit margin bew_i , and let the decision variable bex_i ($i = 1,2,\ldots,7$) denotes the total amount of edible mushrooms sold on day i . Final Pricingy_i can be expressed as

$$y_i = (1+)w_i\ ) *c_i \tag{3}$$

In Eq.c_i denotes the incoming cost of edibles on day i, so the profit of edibles on day ip_i can be expressed as

$$p_i=x_i\ *(y_i\ -c_i\ ) \tag{4}$$

Then the total profit of the superstore for the week is

$$P_{total}=\sum_{i=1}^{7}(p_{i1} + p_{i2} + p_{i3} + p_{i4} + p_{i5} + p_{i6})$$
$$(j = 1,2,\ldots,6,\ ) \tag{5}$$

From the regression analysis above, the equation relationship between sales volume and pricing can be obtained and also used as a constraint.

$$\begin{aligned} y_{i1} &= \beta_{10} + \beta_{11}x_{i1} \\ y_{i2} &= \beta_{20} + \beta_{21}x_{i2} \\ y_{i3} &= \beta_{30} + \beta_{31}x_{i3} \\ y_{i4} &= \beta_{40} + \beta_{41}x_{i4} \\ y_{i5} &= \beta_{50} + \beta_{51}x_{i5} \end{aligned} \tag{6}$$

$$y_{i6} = \beta_{60} + \beta_{61} x_{i6}$$

The optimisation model can be obtained by associating the above equations as

$$P_{total-max} = \sum_{i=1}^{7} \sum_{j=6}^{6} p_{ij}$$

$$\begin{cases} y_{ij} = \beta_{j0} + \beta_{j1} x_{ij} \\ y_{ij} = (1 + w_{ij}) * c_{ij} \\ p_{ij} = x_{ij} * (y_{ij} - c_{ij}) \\ x_{ij}, y_{ij}, p_{ij} >= 0 \\ i = 1,2,\ldots,7 \\ j = 1,2,\ldots,6 \end{cases} \quad (7)$$

The total daily replenishment of edible mushrooms and the pricing strategy were solved based on the optimisation model and the calculations yielded the results as shown in the table below.

Table 3. Results of daily replenishment and pricing strategy of edible mushrooms during the week

Date	daily replenishment(kg)	Pricing strategy(%)
2023-07-01	65.501	33.23
2023-07-02	67.324	99.87
2023-07-03	31.823	106.91
2023-07-04	49.419	85.9
2023-07-05	47.163	92.31
2023-07-06	57.941	92.1
2023-07-07	62.055	61.81

2.2. Multi-objective particle swarm optimisation algorithm to solve the optimisation model

For the 251 individual items in the collected data set, only 27~33 items can be selected to form a vegetable combination every day, which can be regarded as a knapsack problem, and one of the two states exists for each individual item to be taken or not taken, so 0-1 variables are introduced$q_i = 0$ or1 , i=1,2,... ,251.q_i =1 means that this vegetable item is sold on that day, =0 means that this vegetable item is sold on that day.q_i =0 means that this vegetable item is not sold on that day, the mathematical formula is expressed as:

$$q_i = \begin{cases} 0, & \text{Item i is not for sale} \\ 1, & \text{Item i is not for sale} \end{cases} \quad (8)$$

Therefore, using the 0-1 variableq_i of the sum to indicate that the total number of individual items sold on that day is

$$27 \le \sum_{i=1}^{251} q_i \le 33 \quad (9)$$

Let the total quantity of each individual product bes_i , the quantity ordered for each item in the topic can be expressed as if it satisfies the minimum display quantity constraint of 2.5kg:

$$s_i \ge 2.5,\ i=1,2,\ldots,251 \quad (10)$$

Then the pricing of the ith individual product can be expressed as

$$y_i = (1+)w_i\ ) * c_i \quad (11)$$

The final total profitP_{total} can be expressed as

$$P_{total} = \sum_{i=1}^{251} q_i (y_i - c_i)\ * x_i \quad (12)$$

Calculating the regression model of daily replenishment and pricing for each type of individual item yields 251 regression model equations that can be used as equation constraints. The equation generalisation is

$$y_i = \beta_{i0} + \beta_{i1} x_i \tag{13}$$

where.β_{i1} is the coefficient of the independent variable for the ith individual item, and β_{i0} is the coefficient of the constant term of the ith single product.y_i denotes the pricing of the i-th single item, andx_i denotes the total sales volume of the ith single item.

The optimisation model can be obtained by associating the above equation as

$$P_{total-max} = \sum_{i=1}^{251} q_i (y_i - c_i) * x_i$$

$$\begin{cases} y_i = (1 + w_i) * c_i \\ y_i = \beta_{i0} + \beta_{i1} x_i \\ 27 \le \sum_{i=1}^{251} q_i \le 33 \\ s_i \ge 2.5 \\ q_i = \begin{cases} 0 \\ 1 \end{cases} \\ c_i, x_i \ge 0 \\ i = 1,2,\ldots,251 \end{cases} \tag{14}$$

In the optimisation model established above, 27~33 kinds of 251 kinds of single products need to be selected arbitrarily, and the arithmetic is so huge that it cannot be solved directly by programming. Therefore, this paper adopts the multi-objective particle swarm optimisation algorithm and establishes the multivariate planning model for solving.

Step1:Define the objective function

Suppose there are m objective functions, denoted as$f_1(x)$,$f_2(x)$,... ,$f_m(x)$, where x is the decision variable to be solved, i.e., the sales volume of each individual product.

Stpe2:initialises the particle swarm

Set the dimension n of the particle, i.e., the number of decision variables.

Initialise the position and velocity of the individual particles, the position of each particle is represented by an n-dimensional vector and the velocity is also represented by an n-dimensional vector.

Randomly set the individual best position pbest and the global best position gbest for each particle

Step3:Particle Update

Update the velocity and position of the particle according to the current position and velocity by using the equation

$$v_{ij}(t+1) = w * v_{ij}(t) + c_1 r_1 * (pbest_{ij}(t) - x_{ij}(t)) + c_2 r_2 \ (t) * (gbest_{ij}(t) \ - x_{ij}(t) \ ) \tag{15}$$

$$x_{ij}(t+1) = x_{ij}(t) \ + v_{ij}(t+1) \tag{16}$$

where$v_{ij}(t)$ denotes the velocity of particle i in dimension j and$x_{ij}(t)$ denotes the position of particle i in dimension j, w is the inertia weight, andc_1、c_2 is the acceleration factor, ther_1 andr_2 are random numbers.

Step4:Update Individual Best Position and Global Best Position

For each particle, the individual best position pbest is updated by comparing the objective function values of the current position and the individual best position.

For the whole particle swarm, the objective function values of the current position and the global best position are compared and the global best position gbest is updated.

Step5:Check termination conditions

If a preset number of iterations is reached or a global optimal solution is found, the algorithm is stopped; otherwise, return to step 3.

Step6:Output results

Based on the final global best position gbest, an approximate optimal solution to the optimisation problem is obtained.

The final calculations result in the following individual replenishment quantities and pricing strategies for 1 July.

Table 4. Edible mushroom daily replenishment and pricing strategies

product name	daily replenishment (KG)	Pricing strategy (%)	product name	daily replenishment (KG)	Pricing strategy (%)
hairy cabbage	3.17	112.36	Red Pepper	2.87	100.97
Yunnan lettuce	11.43	128.72	Crab mushrooms and mushrooms	2.30	86.12
Artemisia	9.02	142.46	Honghu lotus root	7.00	66.94
Beef head canola	18.34	94.26	Small greens	5.24	130.21
Purple eggplant	3.19	44.25	lettuce	12.31	100.17
Lentinula edodes	18.14	45.44	Yunnan oil wheat	8.41	93.81
broccoli	18.00	58.62	Spinach	13.20	136.32
Lotus Root	25.17	125.33	Houttuynia	2.59	64.44
cabbage moss	2.15	60.15	Millet pepper	19.35	120.11
White jade mushroom	2.00	125.22	Ice grass	11.99	119.98
Green Pepper	27.12	59.09	Enoki mushroom	21.09	77.01
Pleurotus eryngii	3.21	138.00	Yellow cabbage	8.12	96.00
102900011034231	13.23	71.20	Round eggplant	4.11	39.67
Milk cabbage	9.89	53.00	Milk cabbage	6.35	40.18
Pepper Combination	4.80	61.28			

3. Conclusion

The order quantities and selling prices of vegetable commodities were determined by establishing a regression model using the least squares method in conjunction with historical sales and demand. Further, an optimisation model was developed based on the relationship between the total sales volume and the cost-plus pricing equation obtained from the regression model, combined with profit derivation. Through 0-1 integer programming and multi-objective particle swarm optimisation algorithms, the model is solved and calculated iteratively to obtain the daily replenishment quantity and pricing strategy with the maximum return of the superstore in the coming week. Considering the situation of restricted product categories, the model is able to formulate corresponding decision-making strategies for different product categories. The innovation of this study is to establish an accurate model using more accurate methods and comprehensive data to improve the operational efficiency and competitiveness of hypermarkets.

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