Research on Order Allocation Scheme Based on Multi-Objective Planning Model and Comprehensive Evaluation Method

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Abstract: In order to determine whether the production side can meet the demand of the sales side, a multi-objective planning model is developed to compare the usage time of each type of equipment with the production time, and to obtain the production order allocation scheme that meets the minimum overall cost. When the demand exceeds the total capacity, three demand reduction scenarios are developed, and the minimum overall cost is calculated for each scenario. Finally, our recommendations are given for the supply chain company.

Keywords: Order allocation; Integrated cost; Multi-objective planning; Topsis integrated evaluation method; Coefficient of variation method evaluation; Rank and ratio integrated evaluation method; Linear weighted sum method

1. Introduction

1.1Background and work

In this paper, we address the optimal strategy for allocating production orders in a food group. The production, supply and marketing group consist of three parts: the production side, the supply chain company and the sales side. The production side consists of five food processing plants, all of which can produce different products, but all of them have the same processes. On the production side, we consider the issue of capacity competition[1]. Since the same type of equipment can produce different products in parallel or at different times, there are constraints on the capacity of different products. Since demand on the sales side is not always met, the supply chain company's role is to balance demand and supply. On the supply chain side, we need to make a reasonable production order allocation strategy based on the capacity of each factory, taking into account the production cost and logistics cost, in order to maximize the demand on the sales side, and allocate the quantity requested by each sub-warehouse to five factories. In the sales side, the demand quantity of each product is usually determined based on the sales volume, gross margin and the latest competitive products in the market. In case the demand quantity on the sales side is not fully satisfied, the demand quantity on the sales side is reduced according to the production capacity and production cost on the production side and the logistics cost on the supply side, and the demand quantity and order allocation plan for each product are finally determined[2].

Therefore, this paper will build a mathematical model to solve the following problems: according to the production schedule and production capacity of the factories, analyze whether the five factories can meet the demand for goods within two weeks. Based on the results, we rank the overall cost of the five factories from smallest to largest, and use the factory with the smallest overall cost to produce as much as possible, and then develop an order plan to meet the smallest overall cost and analyze the effect.

1.2 Model assumptions

1. It is assumed that different factories can provide goods for different sub-warehouses. That is to say, the quantity of goods required by the Beijing branch warehouse is not necessarily

Only available from the Beijing factory.

2. Assume that the sales end always buys all the products provided by the production end.
3. Assuming that the total weekly supply of the production end is all transferred within the week, there will be no leftovers to the next week.

1.3 Symbol Description

The following Table 1 shows the description of the symbols

Table 1 Symbol Description

Symbols	Description
i	The i-th device in each process
j	The jth product
x	Time required for thermal processing process
y	Time required for inner packaging process
z	Time required for quick-freezing process
A	Productivity Matrix
B	Time Matrix
f	Production capacity

2. Construction and solution of minimum time model based on multi-objective planning

2.1 Output per process based on capacity x time

2.1.1 Formation of capacity matrix

The capacity data of the five factories are summed up according to each equipment to obtain the total capacity of each type of equipment for different products in the five factories. The specific matrix A is shown in Figure 1.

$$
\begin{Vmatrix}
0 & 4977 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 7490 & 2590 & 3083.333 \\
0 & 6547 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 6054 & 2940 & 1800 \\
0 & 0 & 0 & 0 & 1025 & 10260 & 0 & 0 & 0 & 9302 & 10338 & 8000 \\
0 & 4818 & 15840 & 0 & 0 & 0 & 9600 & 5333 & 0 & 0 & 8400 & 4500 \\
0 & 5207 & 0 & 0 & 0 & 2539 & 1926 & 1070 & 0 & 0 & 5180 & 3700 \\
0 & 0 & 0 & 8061 & 0 & 0 & 10639 & 5910 & 0 & 0 & 15400 & 11000 \\
0 & 4598 & 0 & 0 & 0 & 0 & 5916 & 3287 & 0 & 0 & 11433 & 8166.667 \\
7369 & 24024 & 0 & 54207 & 0 & 9039 & 15529 & 8627 & 0 & 0 & 17156 & 33700 \\
2618 & 34873 & 0 & 2250 & 0 & 0 & 5680 & 3156 & 0 & 0 & 8229 & 9600 \\
0 & 7431 & 0 & 4606 & 0 & 0 & 9600 & 5333 & 0 & 0 & 10360 & 18500 \\
0 & 0 & 0 & 21112 & 0 & 4234 & 0 & 0 & 4733 & 0 & 7350 & 4200 \\
0 & 0 & 0 & 36000 & 0 & 0 & 9260 & 4530 & 0 & 0 & 13310 & 8400 \\
0 & 14657 & 0 & 2555 & 0 & 0 & 1621 & 624 & 0 & 0 & 5400 & 2700 \\
2287 & 0 & 0 & 0 & 0 & 0 & 7784 & 4179 & 0 & 0 & 10605 & 6900 \\
0 & 26214 & 0 & 0 & 0 & 0 & 2780 & 1167 & 0 & 0 & 1375 & 1040
\end{Vmatrix}
$$

Figure 1 Matrix A

Let a line vector of A be A_j, which represents the line vector composed of the jth line, that is, the capacity vector of j products. A_{kj} is represented as component 1 of the line vector A_j, k=1 represents the equipment related to the hot processing process, k=2 represents the equipment related to the inner packaging process, and k=3 represents the equipment related to the quick-freezing process.

2.1.2 Calculate the output of each process

The processing processes of the product include thermal processing, inner packaging and quick-freezing, indicating that the total output of the nth process is equal to the total output of the nth+1st process, implying that the total output of the thermal processing process = the total output of the inner packaging process = the total output of the quick-freezing process. The total output of the thermal processing process for the jth product can be expressed as $A_{1j}B_{1j}$.

2.2 Minimum time model and solution based on multi-objective planning

List the multi-objective planning model.

With i denoting different classes of equipment and j denoting different kinds of products, the working hours of the equipment related to the thermal processing process can be x_{ij}, the working hours of the equipment related to the inner packaging process can be y_{ij}, and the working hours of the equipment related to the quick-freezing process can be z_{ij}.

Let a column vector B_j be $(x_{1j}\ x_{2j} \dots\dots x_{6j}\ y_{1j} \dots\dots y_{4j}\ z_{1j}\ z_{2j})^T$, the vector is the time matrix of using equipment. B_{kj} is denoted as the component of vector B_j of components, k is the kth equipment, k=1 represents the equipment related to hot processing process, k=2 represents the equipment related to inner packaging process, k=3 represents the equipment related to quick-freezing process, that is, $B_{kj} = (x_{1j}\ x_{2j} \dots\dots x_{6j})^T$, $B_{kj} = (y_{1j} \dots\dots y_{4j})^T$, $B_{kj} = (z_{1j}\ z_{2j})^T$.

$$f_1 = \sum_{j=1}^{15} x_{ij}, i = 1,2,3,4,5,6$$

$$\min \begin{cases} f_2 = \sum_{j=1}^{15} y_{ij}, i = 1,2,3,4 \\ f_3 = \sum_{j=1}^{15} z_{ij}, i = 1,2 \\ f_4 = A_j B_j, j = 1,2,3\dots15 \end{cases} \tag{1}$$

$$\text{s.t.} \begin{cases} A_{1j}B_{1j} = A_{2j}B_{2j} = A_{3j}B_{3j} = s_j \\ j = 1,2,\dots\dots15 \end{cases}$$

This is a more complex multi-objective planning model, which is solved using the ideal point method[3].

Step1:Decompose the multi-objective into a simple single-objective linear programming.

$$(P1)\begin{cases} \min \quad f_1 = \sum_{j=1}^{15} x_{ij}, i = 1,2,3,4,5,6 \\ \text{s.t.} \begin{cases} A_{1j}B_{1j} = A_{2j}B_{2j} = A_{3j}B_{3j} = s_j \\ j = 1,2,\dots..15 \end{cases} \end{cases}$$

$$(P2)\begin{cases} \min f_2 = \sum_{j=1}^{15} y_{ij}, i = 1,2,3,4 \\ \text{s.t.} \begin{cases} A_{1j}B_{1j} = A_{2j}B_{2j} = A_{3j}B_{3j} = s_j \\ j = 1,2,\dots..15 \end{cases} \end{cases} \tag{2}$$

$$(P3)\begin{cases} \min f_3 = \sum_{j=1}^{15} z_{ij}, i = 1,2 \\ \text{s.t.} \begin{cases} A_{1j}B_{1j} = A_{2j}B_{2j} = A_{3j}B_{3j} = s_j \\ j = 1,2,\ldots\ldots 15 \end{cases} \end{cases} \tag{3}$$

$$(P4)\begin{cases} \min f_3 = \sum_{j=1}^{15} z_{ij}, i = 1,2 \\ \text{s.t.} \begin{cases} A_{1j}B_{1j} = A_{2j}B_{2j} = A_{3j}B_{3j} = s_j \\ j = 1,2,\ldots\ldots 15 \end{cases} \end{cases} \tag{4}$$

Step2:Construct the following evaluation function with the solution of the above single-objective programming.

$$\min h(f(x)) = \sqrt{\sum_{n=1}^{4}\left(f_n(x) - f_n^*\right)^2} \tag{5}$$

Step3:Call the function f=objfun() in Python.

$$\mathrm{f} = h(f(x)) = \sqrt{\sum_{n=1}^{4}\left(f_n(x) - f_n^*\right)^2} \tag{6}$$

$$\begin{gathered} \min h(f(x)) = \sqrt{\sum_{n=1}^{4}\left(f_n(x) - f_n^*\right)^2} \\ \text{s.t.} \begin{cases} A_{1j}B_{1j} = A_{2j}B_{2j} = A_{3j}B_{3j} = s_j \\ j = 1,2,\ldots\ldots 15 \end{cases} \end{gathered} \tag{7}$$

Step4:

Finally solve this nonlinear program with [x,fval,exitflag]=fmincon(@objfun,x0,A,b,[],[],lb,[])[4].

where A is the coefficient matrix and b is the rightmost constant, yielding the result. The working time and production differs for each type of equipment.

By comparing the total time of each type of equipment with the total production time, the sum of time of each type of equipment is less than the total production time, so five plants can complete the demand for the quantity of goods in two weeks.

3. Construction and solution of comprehensive cost evaluation system based on topsis integrated evaluation method

3.1 Comprehensive cost evaluation system of each plant based on topsis integrated evaluation method

The comprehensive cost of a factory includes fixed cost, variable cost and transportation cost, and the evaluation of a factory's comprehensive cost The evaluation of the comprehensive cost of a factory is based on the combination of these three aspects.

First, the data of the three costs are processed so that they have the same dimensions to facilitate comprehensive evaluation. For fixed costs, the five factories in Beijing, Shanghai, Shenzhen, Jinan, and Hangzhou are 170,000, 210,000, 110,000, 140,000, and 0. For variable production costs, the prices of different products produced by different factories are different, but the trends are the same (e.g., the prices of p03 and p04 are the same for each factory), so we average the variable prices of different products for each factory and use this as the average variable cost for each factory. The average of the prices of different products in each factory is used as the average variable cost of each factory. Finally, we calculate the freight costs by first averaging the freight prices of each plant with different case sizes to the branch warehouse (for the same reason as above) to obtain the average freight cost of each plant to each branch warehouse[5].

Then, we use the coefficient of variation method to calculate the weight of each bin based on the distance from each bin to each plant.

3.1.1 Freight rate evaluation system of each plant based on the coefficient of variation method

$$R_{ij}=\begin{bmatrix} 50 & 1329 & 2301 & 2279 & 1401 & 1296 \\ 1249 & 50 & 1411 & 1411 & 150 & 826 \\ 2212 & 1382 & 50 & 139 & 1218 & 1407 \\ 443 & 818 & 1832 & 1843 & 880 & 853 \\ 1248 & 115 & 1340 & 1365 & 92 & 727 \end{bmatrix} \tag{8}$$

The coefficient of variation method is a direct use of the information contained in each indicator to obtain the weights of the indicators by calculation[6]. It is an objective weighting method.

Step1:First need to standardize the indicators.

$$R_{ij}^{'}=\begin{bmatrix} 0 & 0.96021 & 1 & 1 & 1 & 1 \\ 0.554579 & 0 & 0.60462 & 0.594393 & 0.044309 & 0.173989 \\ 1 & 1 & 0 & 0 & 0.860199 & 0.562239 \\ 0.181776 & 0.576577 & 0.791648 & 0.796262 & 0.601986 & 0.221441 \\ 0.554117 & 0.048799 & 0.573079 & 0.572897 & 0 & 0 \end{bmatrix} \tag{9}$$

Step2: Calculate the mean value of indicators $A_j=\frac{1}{n}\sum_{i=1}^{m} r_{ij}$

Step3: Calculate the standard deviation of the index $S_j=\sqrt{\frac{1}{n}\sum_{i=1}^{m}\left(r_{ij}-A\right)^2}$

Step4: Derive the coefficient of variation.

$$V_j = (1.0525821.070131\ 0.7669430.769598\ 0.945991\ 0.787414) \tag{10}$$

Step5: Derive the weights.

$$W_{ij} = (0.195188\ 0.198442\ 0.14222\ 0.142712\ 0.175422\ 0.14 \tag{11}$$

The average freight rate sent to each bin * the weight of each bin was then used to obtain the combined freight rate for each plant.

The results of data processing are as Table 2.

Table 2 Combined shipping cost per plant

a_{ij}	Fixed Costs	Variable Costs	Shipping Fee
Beijing	170000	40.27	1.01
Shanghai	210000	35.81	0.64
Shenzhen	110000	29.64	0.87
Jinan	140000	26.83	0.8
Hangzhou	0	28.357	0.63

3.1.2 Five plants were scored based on the Topsis integrated evaluation method

After finding out the three costs, the different plants are rated and ranked by Topsis comprehensive evaluation method[7].

Step1: Processing of data.

Indicator Positivization.

$$A=\begin{bmatrix} 40000 & 0 & 0 \\ 0 & 4.46 & 0.37 \\ 100000 & 10.63 & 0.14 \\ 70000 & 13.44 & 0.18 \\ 210000 & 11.913 & 0.38 \end{bmatrix} \tag{12}$$

Standardization of indicators[8].

$$Z=\begin{bmatrix} 0.1625 & 0 & 0 \\ 0 & 0.2090 & 0.6409 \\ 0.4062 & 0.4981 & 0.2425 \\ 0.2844 & 0.6298 & 0.3118 \\ 0.8531 & 0.5582 & 0.6582 \end{bmatrix} \tag{13}$$

Step2: Calculate the score S.

Define the distance between the i-th (i=1,2,...,n) evaluation object and the maximum value.

Define the distance between the i-th (i=1,2,...,n) evaluation object and the smallest value.

$$S=\begin{bmatrix} 0.1245 \\ 0.4148 \\ 0.5239 \\ 0.5324 \\ 0.9443 \end{bmatrix} \tag{14}$$

Finally, the scores of the five plants were obtained, i.e., Beijing, Shanghai, Shenzhen, Jinan, and Hangzhou were 0.1245, 0.4148, 0.5239, 0.5324, and 0.9443, where Hangzhou has the highest score, indicating that Hangzhou has the lowest comprehensive cost, so The highest score indicates that Hangzhou has the lowest overall cost, so Hangzhou outsourced factories are given priority for production and distribution.

3.2 Order allocation to meet the minimum integrated cost under the three derogation scenarios

The following is an example of the Beijing factory.

Let the product production volume be p_j, representing the production volume of product category j.

$$\max\left\{P=\sum_{j=1}^{15} p_j\right. \tag{15}$$

$$\text{s.t.}\begin{cases} \sum_{j=1}^{15} x_{ij} \le 240, i=1,2,3,4,5,6 \\ \sum_{j=1}^{15} y_{ij}, i=1,2,3,4 \le 240 \\ \sum_{j=1}^{15} z_{ij}, i=1,2 \le 240 \\ A_{1j}B_{1j}-A_{2j}B_{2j}=0 \\ A_{1j}B_{1j}-A_{3j}B_{3j}=0 \\ A_jB_j \le 240, j=1,2,3\ldots15 \\ p_j>0 \\ j=1,2,\ldots\ldots15 \end{cases} \tag{16}$$

Once the maximum production is obtained, the allocation of each product is started. Priority is given to the combined cost ranking of each plant derived in the first step If the rankings are the same, the allocation is made according to the size of the freight[9].

Once the maximum production volume is obtained, the allocation of each product is started. In case of equal ranking, the allocation is done according to the size of the freight cost, and the final allocation strategy with the lowest overall cost is as Figure 2.

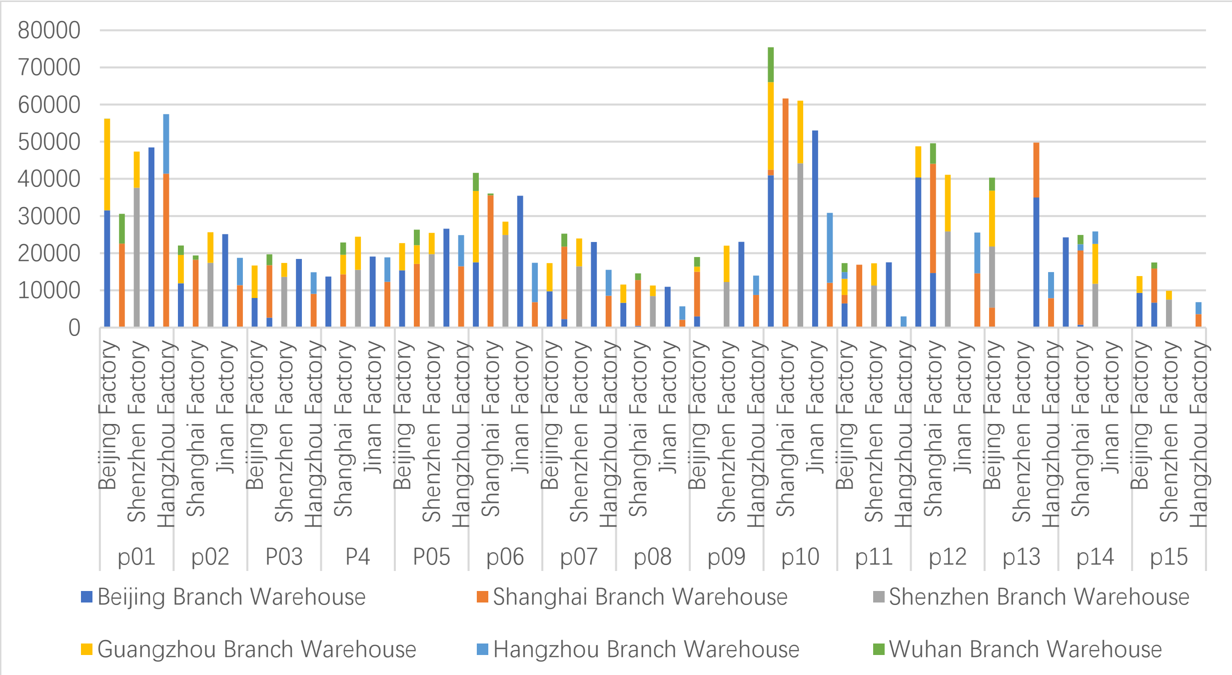

Figure 2 The final allocation strategy with the lowest overall cost

4. Order distribution plan and proposal

In order to achieve the lowest overall cost, the plant with the lowest overall cost should be used for production and distribution in order to meet the requirements for the quantity of goods to be delivered. If the overall costs are the same, the plant with the lowest transportation costs should be used. This principle can be referred to as the "Least Overall Cost - Least Transportation Cost" principle[10]. (hereinafter referred to as: Principle)

5. Conclusion

5.1 Order allocation schemes and conclusions in different cases

In summary, in this paper, by constructing two objective functions, capacity × time = supply and capacity minimization, and solving them by the ideal point method, it is concluded that five factories can fulfill the required quantity of wants within two weeks. Then, in order to calculate the order solution that satisfies the integrated cost minimization. We use different methods to deal with fixed cost, variable cost and logistics cost, and aggregate the three costs and use TOPSIS comprehensive evaluation method to come up with practical solutions such as giving priority to Hangzhou outsourced factory for distribution.

In addition, this paper also considers how to deal with the situation if the total capacity of five factories cannot meet the total demand of the quantity wanted, and the equal proportional reduction may not meet the will of the sales end. First, the quantity of each product is increased by 15% so that it exceeds the total capacity to a certain extent. Then, according to the wishes of the sales side, we will reduce the quantity requested. Second, according to the wishes of the sales side, we set up three reduction methods, which are ranked by sales volume, gross margin and a combination of both. Then, in order to satisfy the purpose of maximizing the utilization of capacity, we construct a multi-objective planning equation to satisfy the working hours of each type of equipment less than or equal to 240 hours (objective function 1) and the working hours of producing each product less than or equal to 240 hours (objective function 2), and solve it by linear weighted sum method to get the reduction ratio and the reduced scheme. Finally, after obtaining the three different reduction schemes, the orders are allocated using a specific allocation method to satisfy the minimum integrated cost.

5.2 Model Evaluation

5.2.1 Model Advantages

In comparing the comprehensive cost of each plant, two comprehensive evaluation methods are used successively to establish a complete comprehensive cost evaluation system, which can reflect the comprehensive cost of each plant more objectively and comprehensively, facilitate the solution of the comprehensive and cost minimization problem, and make the results more close to the actual situation. In the multi-objective planning model, weights are cleverly introduced to solve the problem of finding the output of each plant under different reduction schemes by assigning weights to different objective functions. It is more intuitive and easy to understand, and it also increases the flexibility of the model to solve the output of each plant under different reduction schemes by adjusting the size of the weights.

5.2.2 Model Disadvantages

The model gives priority to the problem of comprehensive cost when formulating the allocation scheme, which theoretically satisfies the requirements of the topic, but in the actual allocation process, it may lead to the product in a certain place being supplied by plants in multiple places, reducing the transportation efficiency and even increasing the transportation loss. And because the equipment required for each product is different, in order to achieve the target allocation scheme, some plants' individual equipment needs to work continuously for two weeks in order to achieve the target allocation scheme, which is also difficult to achieve in actual production.

5.2.3 Extension of the model

The model can be used not only to determine the production and allocation scheme of a factory, but also to solve other similar problems, such as How to allocate the supply of different products in each store of a convenience store chain to obtain the maximum profit with the smallest possible surplus

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