Research on Ordering and Transportation Strategy of Raw Materials for Manufacturing Companies Based on Time Series Model and Monte Carlo Stochastic Simulation

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Abstract: A company needs to develop a series of ordering and forwarding strategies to maximize its profitability when it purchases three raw materials from a supplier for the production of decorative building panels, which are delivered to its warehouse by a forwarder. In this paper, we analyze the past cooperation data between the company and its suppliers and forwarders to build a mathematical model and find the optimal solution. The problem is based on quantitative analysis, so it can largely avoid unnecessary expenses caused by subjective and empirical judgments of enterprise managers, and has strong practical significance. In this paper, the 50 most important suppliers selected by considering the past supply characteristics of 402 suppliers are used as the base data. To determine the minimum number of suppliers required. Integrating factors such as raw material cost and transportation loss rate, the weekly ordering and transshipment plan for the next six months will be developed based on the selected suppliers. Based on this, we introduce the goal of purchasing as much as possible A and as little as possible C, develop a new ordering and forwarding program, and conduct a predictive analysis of the program's implementation effects.

Keywords: K-Means Cluster Analysis; Time Series; Monte Carlo Model; Cluster Analysis; Multi-objective optimization.

1. Introduction

The enterprise can produce decorative building panels from wood and other plant fibers as raw materials with a maximum of 28200 cubic meters. The required raw materials can be classified as A, B, and C. The enterprise orders raw materials from suppliers and commissions forwarders to transport the materials to the enterprise's warehouse.

The main tasks of this paper are, first, to find out the minimum number of suppliers needed to meet the production demand, second, to calculate the most economical ordering solution, and third, to calculate the transfer solution with the minimum loss. In this regard, first, the minimum number of suppliers that can guarantee the adequacy of raw materials is calculated using the supply expectation derived from problem 1. Second, the linear programming model is used to solve for the optimal weekly order quantities for the three raw materials. Then, in order to allocate the total weekly order quantity to suppliers, this paper uses the time series analysis method to obtain the reference value of supply quantity for the next 24 weeks, and calculates the ratio of individual supplier reference value to the sum of the total reference values, and allocates the orders to suppliers by multiplying the ratio of the reference value by the best order quantity of the corresponding raw materials to develop the future weekly ordering plan. Considering the computational volume and timeliness issues, this paper uses Monte Carlo simulation to solve for the optimal transit scheme. Finally, the scheme is evaluated by K-Means clustering analysis and found to be consistent with the past data. Based on this, the ordering and transshipment scheme is reformulated to achieve the modified ordering and transshipment scheme with the purpose of selecting more Class A as well as less Class C raw materials by the incentive planning model[1]. The data this study uses is provided by CUMCM 2021.

2. Model assumptions and notation

2.1 Model assumptions

1. Assume that the supply and order quantity data are smooth and a time series analysis model can be used.
2. Assume that the company has stocked enough raw materials in its inventory for two weeks of production.
3. Ignore the difference in quality of raw materials and products.

2.2 Notations

The symbols are described in Table 1.

Table 1 Notations

Symbols	Meaning
X	Ordered amount of raw material A
Y	Ordered amount of raw material B
Z	Ordered amount of raw material C
$Upper_*$	Maximal amount of raw material * to be ordered
α	Quantities of a certain type of raw material needed for one unit of product
AoPR	Enterprise weekly maximum capacity (cubic meters)
S_{it}	The transshipment scheme of the supplier
μ	The willingness coefficient of raw material

3. Model construction and solving

After completing the evaluation of all suppliers, we obtained the trustworthiness of each supplier and its acceptable order quantity. To estimate each supplier's future capacity, we use the product of the trustworthiness level and the acceptable order quantity as a forecast of the supplier's actual supply quantity (which is also the supplier's importance to us)[2]. For each supplier, we have a reference future supply quantity, on the basis of which we can further study the specific ordering scheme.

For the three different goods A, B, C, if there is no preference (second question), we can unitize them according to the amount of products they can produce per cubic meter, and rank all suppliers in descending order (in order of importance) according to the amount of products they can produce according to the forecasted supply, and select suppliers from the highest to the lowest until the maximum capacity demand is met, so that we can find the minimum number of suppliers. The most economical raw material ordering solution can be obtained by combining the selected supplier base with the consideration of the loss rate, and the least lossy transfer solution can be developed accordingly[3].

If there is a selection preference (third question), such as purchasing more raw material A and less raw material C, we need to classify the suppliers according to the type of raw material and rank all suppliers in descending order according to the amount of products that can be produced from the forecast supply, and according to the preference, the supplier of raw material A is preferred, then the supplier of raw material B, and finally the supplier of raw material C until the maximum capacity demand is met. Based on these newly selected suppliers, the best ordering and forwarding solution is studied.

3.1 Optimal transit solution model

3.1.1 Calculation of the minimum number of suppliers based on supply expectations

Based on Supplier ranking is performed to accumulate the supply expectation until the supply expectation reaches 1.1 times the weekly capacity. In the sequential method, when the number of required suppliers is 40, the supply expectation equals 31068 m^3, which is 1.107 times the weekly capacity and basically meets the requirements.

3.1.2 Determination of order total based on Linear Programming

The manufacturer needs to reduce the purchase cost as much as possible while supplying sufficient quantities of each type of raw material and not exceeding the total amount of each type of raw material from the 40 suppliers selected above. Here we ignore the costs associated with transportation and storage.[4]

For the calculation of purchase cost, let the unit price of raw materials of category C be p, then the unit prices of raw materials of category A and B are 1.2p and 1.1p respectively.

(1) Determination of objective function and constraint conditions

According to the above analysis we can obtain the following linear programming problem.[5]

Objective function.

$$\min\ 1.2Xp + 1.1Yp + Zp \tag{1}$$

Binding Conditions.

$$s.t.\ \frac{X}{\alpha_A} + \frac{Y}{\alpha_B} + \frac{Z}{\alpha_C} \geqslant AoPR \tag{2}$$

$$X \leqslant Upper_A \tag{3}$$

$$Y \leqslant Upper_B \tag{4}$$

$$Z \leqslant Upper_C \tag{5}$$

$$X, Y, Z \geqslant 0 \tag{6}$$

(2) Solving linear programming problems

In this paper, we use the linprog function of matlab to solve the linear programming model, and get the results in Table 2.

Table 2 Linear programming to find the total amount of raw materials ordered per week

A	B	C
10471.2	3118.5	4336.56

Observing the data, it can be seen that the total amount of raw materials ordered per week is the lowest because of the high quantity and high unit price of raw material B consumed per unit of product produced, which is the least cost-effective among the three raw materials.

3.1.3 Determination of order allocation weight based on Time Series model

Since the forecast of supply quantity by supply expectation only is equivalent to the assumption that the supplier's supply quantity is not affected by time, many factors in reality are ignored, such as the possible seasonal fluctuation of the supplier's production capacity, and different suppliers are affected by time to a different extent[6].

The study found that there is indeed a trend of seasonal variation in the supplier's supply on a weekly basis, so a time series model is considered to forecast the supplier's supply for the next 24 weeks.

A time series is a numerical sequence of specific phenomena composed in chronological order, and this model can describe the pattern of past data. There are three core components of time series analysis, which are describing historical experience, analyzing data patterns, and predicting the future.

Since the data reflects the instantaneous level at each point of cooperation and does not have an exponential upward trend, the numerical element is a point-in-time series and the time series model is classified as a superposition model, i.e.

$$Y = T + S + C + I \tag{7}$$

We used the SPSS time series analysis function to analyze the cooperation between firms and suppliers and adopted the expert selection method to screen out the dependent variables that can better simulate the real situation with a set of models that are more explanatory to the total results. In this paper, we choose among the following three models: the simple seasonality model, the Winters multiplier model, and the ARIMA model.[7]

(1) Simple seasonal model

By observing the line statistical graphs of past cooperation data of producers and suppliers, it is found that some of the data do not have significant seasonal effects over time, and we judge that they contain a stable seasonal component. Therefore, a simple seasonal model is considered as the exponential smoothing model.

(2) Winters multiplier method

In addition to some cooperative data with a stable seasonal component and no trend, we also found data with a linear trend and a seasonal component that changed over time, so we considered introducing a Winters multiplication model for fitting[8].

(3) AR model, MA model, and ARIMA model

AR models, also known as autoregressive models, are suitable for predicting events whose future development is influenced only by their own past properties. the autoregressive model of order P is formulated as follows.

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \dots + \alpha_p y_{t-p} + \varepsilon_t \tag{8}$$

However, this model does not fit well for events that are strongly influenced by the environment in the same period, and other models need to be introduced.

The MA model is also known as the moving average model. The q-order moving average model is formulated as follows.

$$y_t = \varepsilon_t + \beta_1 \varepsilon_{t-1} + \beta_2 \varepsilon_{t-2} + \dots + \beta_q \varepsilon_{t-q} \tag{9}$$

The ARIMA model combines the advantages of both of these models.

$$y_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i y_{t-i} + \varepsilon_t + \sum_{i=1}^{q} \beta_i \varepsilon_{t-i} \tag{10}$$

(4) Missing data filling

Due to the existence of enterprises and suppliers in the data with a large time span of cooperation, the time series model cannot be fitted perfectly, so this special case requires us to build another model to fit. The suppliers that need to be solved by constructing models are S395, S282, and S348.

(5) Time series fitting results

Using SPSS for time series analysis, we obtained the reference supply (in terms of one cubic meter of product) for the next 24 weeks for the selected 40 suppliers.

(6) Order allocation

According to the calculated reference supply quantity, we define the order allocation rules as follows.

$$Ord_{i,t} = \frac{P_{i,t}}{\sum\limits_{k=1}^{n} P_{k,t}} X \tag{11}$$

As a result, we obtained the ordering strategy of the producer for the next 24 weeks, with the following partial results as shown in Table 3.

Table 3 The company's ordering plan for the next 6 weeks to the Class A raw material suppliers

ID	W001	W002	W003	W004	W005	W006
S143	998.71618	370.198693	707.838	695.492501	635.753412	635.883087
S201	1384.10449	0	0	0	0	0
S229	4225.60557	6705.58569	5200.8081	4872.71641	4462.4244	4761.60312
S273	54.9937727	56.2207925	67.8938259	76.644424	86.8480454	91.9998764
S275	2313.18687	1915.20272	2207.40188	2438.90863	2316.34362	2748.988
S282	830.766396	880.285984	1017.65309	935.817968	796.014769	816.576171
S307	0	0	13.9154491	10.2006769	1382.81835	599.730778
S329	2096.85739	1920.28166	2104.68909	2455.29083	2128.28361	2259.44801
S348	786.857692	728.086415	851.3057	756.831377	725.906856	690.03151
S352	417.132789	445.258181	573.933855	532.859999	474.515178	467.298933
S395	1592.97884	1680.07987	1955.76101	1926.43719	1692.29175	1629.64052

3.1.4 Transit scenario development based on Linear Programming

Based on the ordering scheme defined above, it is now necessary to arrange forwarders for suppliers with non-zero weekly deliveries and to keep the transport losses as low as possible. In this paper, the transport losses are calculated by multiplying the supply quantity by the loss rate and the price coefficient of the three raw materials. In addition, the maximum capacity of each forwarder is 6000 m^3 per week. Accordingly, we obtain the following linear programming model[9].

Objective function.

$$min \sum_{t=1}^{T} \sum_{i=1}^{n} X_{it} S_{it} P_t \tag{12}$$

$$Where\ S_{it} = (S_{it}^{(1)}, S_{it}^{(2)} S_{it}^{(3)}, \ldots, S_{it}^{(8)}) \tag{13}$$

$$P_t = (P_t^{(1)}, P_t^{(2)}, P_t^{(3)}, \cdots, P_t^{(8)})^T \tag{14}$$

where X_{it} denotes the supply of the i_{th} supplier in week t, S_{it} denotes the transshipment scheme of the i_{th} supplier in week *t*, and P_t denotes the transportation loss rate of each transshipment provider in week *t*.

For raw materials transported through the same forwarder, there are constraints.

$$\text{Subject to: } \sum_{i=1}^{n} X_{it} S_{it}^{(k)} \leqslant 6000 \text{ where } k = 1, 2, 3, \cdots, 8\ for\ all\ t \tag{15}$$

Since the constraints require too many variables to be considered, this paper adopts a Monte Carlo simulation approach, i.e., iteratively simulating the transit options available to each supplier. The approximate range of each variable is derived from the constraints, and then several sets of experimental points are generated with random numbers in the constraint range, and it is verified whether all constraints are satisfied, and if they are satisfied, they are divided into feasible groups, and then the maximum or minimum value of the function is found from the feasible groups. After the Matlab programming solution, the transit scheme for the next 24 weeks is obtained, and some results are shown below as shown in Table 4.

Table 4 Transit program for the next 6 weeks

Suppliers	Raw Materials	W001	W002	W003	W004	W005	W006
S031	B	7	7	4	2	8	3
S037	C	6	2	1	3	6	4
S040	B	7	7	4	2	8	3
S055	B	7	7	4	2	8	3
S074	C	6	2	1	3	6	4
S108	B	5	5	4	6	8	5

3.1.5 Scenario testing based on K-Means Cluster Analysis

The general idea of K-Means is as follows: first, choose K points as the initial center of mass, assign each point to the nearest center of mass, form K clusters, and recalculate the center of mass of each cluster. This step is repeated until the center of mass no longer changes.[10]

(1) Analysis of the effect of the ordering scheme

We performed cluster analysis on the suppliers based on the data from the past 240 weeks and compared the cluster results with the data from the ordering scheme. For example, when K=4, suppliers numbered 151 and 201 were grouped into one category, and their data in the ordering scheme showed a difference from the other suppliers; suppliers numbered 140 were grouped into a separate category because their data were much larger than the other individuals, and their half-yearly averages were larger than the remaining suppliers in our scheme. The implementation of the ordering scheme model is superior due to the consistency of the model data with the past data.

(2) Analysis of the effect of the transshipment scheme

Similarly, we conducted a cluster analysis of the eight forwarders, and the results are shown in Table 5. From the table, it can be seen that by analyzing the previous data, forwarders #3 and #4 are grouped into one cluster, while the rest of the forwarders form another cluster. The statistics of the transshipment scheme given in this paper show that the transshipment volumes of transshipment No. 3 and No. 4 do differ from other transshipment providers. Therefore, the forwarding scheme model is consistent with the historical data pattern.

Table 5 Forwarder Cluster Analysis Results

ForwardersID	Clustering	Distance
T1	1	4.563
T2	1	1.963
T3	2	2.408
T4	2	2.408
T5	1	2.021
T6	1	6.479
T7	1	3.263
T8	1	3.737

3.2 Modification of the ordering scheme and the transit program

Since each cubic meter of product requires 0.6 cubic meters of Class A raw materials or 0.66 cubic meters of Class B raw materials or 0.72 cubic meters of Class C raw materials. After taking transportation and storage costs into account, the firm should purchase as much raw material of category A and as little raw material of category C as possible. In this paper, we adopt the method of multi-objective optimization to minimize the purchase cost and transit cost simutaneously in which the objective function coefficients we introduce μ as the willingness coefficient in the objective function coefficients of the original linear programming model, which serves to add the competent assignment to the purchase of various types of raw materials. The multi-objective optimization model is obtained as follows.

$$min\sum_{i=1}^{n}\sum_{t=1}^{T}1.2\mu x_{it1}+1.1x_{it2}+\frac{1}{\mu}x_{it3} \tag{16}$$

$$min\sum_{k=1}^{3}\sum_{t=1}^{T}\sum_{i=1}^{n}X_{itk}S_{it}P_t \tag{17}$$

where μ is the willingness coefficient, let μ = 0.5.

subject to:

$$\sum_{k=1}^{3}\sum_{i=1}^{n} X_{it} S_{itk}^{(m)} \le 6000 \text{ where } m = 1,2,3,\cdots,8 \text{ for all } t \tag{18}$$

$$\begin{cases} \sum_{i=1}^{n} X_{it1} \le \text{ Upper } A \text{ for all } t \\ \sum_{i=1}^{n} X_{it2} \le \text{ Upper } B \text{ for all } t \\ \sum_{i=1}^{n} X_{it3} \le \text{ Upper } C \text{ for all } t \end{cases} \tag{19}$$

$$\frac{\sum_{i=1}^{n} X_{it1}}{\alpha A} + \frac{\sum_{i=1}^{n} X_{it2}}{\alpha B} + \frac{\sum_{i=1}^{n} X_{it3}}{\alpha C} \ge AoPR \text{ for all } t \tag{20}$$

3.2.1 Modified ordering scheme and transit scheme

The Multi-objective optimization model is solved by applying the Monte Carlo simulation algorithm after modifying the conditions, and then the time series model and order allocation method of the second question are applied to derive the results. Some of the results are shown in Table 6 and Table 7.

Table 6 Modified future subscription program

Suppliers	Raw Materials	W001	W002	W003	W004	W005	W006
S031	B	175.2851	12.75468	46.88782	68.19666	100.0457	19.81552
S037	C	29.73106	55.91725	51.1007	43.22286	29.9128	28.28324
S040	B	184.1379	9.247144	40.51108	92.0655	157.5523	15.69999
S055	B	59.01855	12.11695	40.88618	26.38134	93.74363	18.5961
S074	C	5.800192	5.88122	7.354147	6.961158	6.257377	7.829558
S108	B	546.0944	94.36216	3343.343	205.8018	699.687	165.6241

Table 7 Modified Future Transit Program

Suppliers	Raw Materials	W001	W002	W003	W004	W005	W006
S031	B	5	1	4	1	4	1
S037	C	8	8	4	5	5	2
S040	B	5	1	4	1	4	1
S055	B	5	1	4	1	4	1
S074	C	8	8	4	5	5	2
S108	B	7	2	4	8	5	5

Applying cluster analysis to evaluate the effectiveness of the ordering and transit scenarios, the predicted data was found to be in good agreement with the historical data. Therefore, the two programs were judged to be effective.

4. Conclusion

This paper uses traditional time series analysis models to effectively analyze and simulate data with seasonal fluctuations. Also, it solves multi-objective optimization poblem with complex constraints using Monte Carlo simulation methods with less arithmetic power and time. Furthermore, the paper uses the property of cluster analysis method to classify individuals with similar characteristics and assesses the effectiveness of the solution based on the expected data and historical data presenting consistency.

However, the time series model focuses on analyzing historical data and the influencing factors of the objects themselves, which is not ideal for predicting the current and future influencing factors of the social environment, and the results may appear to be poorly considered.

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