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Research on the Decision Model for Self-Production and Outsourcing Choices under Limited Production Capacity

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Abstract: Problem statement: In the face of competitive environments with uncertain demands and a trend toward High-Mix, Low-Volume (HMLV) production, self-production or direct outsourcing has troubled decision-makers of enterprise for a long time. In the previous studies, not much has been written about the topic. **Approach:** Therefore, this study applies the Analytic Hierarchy Process (AHP) to investigate the topic through either qualitative or quantitative decision-making factors that influence enterprise decision making, as well as through the viewpoint of comparative advantage. **Results:** Besides considering relevant factors in decision making, this study also derives a decision-making model as the basis for enterprises to choose from self-production and outsourcing under limited production capacity. **Conclusion:** Through weighting the importance of each decision factor and proposal by the company's decision maker based on their strategic needs and through eigenvector calculations, the company can obtain an optimal solution, faced with the two choices, based on model calculations. Also, based on the importance priority of each proposal in the decision matrix, the company can conduct production planning and devise purchasing plans.

Key words: Analytic Hierarchy Process (AHP), self-production, outsourcing, High-Mix, Low-Volume (HMLV), Fuzzy Nonlinear Programming (FNLP), Fuzzy Geometric Programming (FGP), self-production, trade-offs, market niche, Strategic decision factors, production capacity

INTRODUCTION

The production operation system is defined as a transformation procedure, a procedure in which enterprises apply their production processes for transforming limited resources to customer-demanded products or services. In the face of fierce market competition and under the impact of more diversified product demands, there is a growing trend toward High-Mix, Low-Volume (HMLV) manufacturing. However, an enterprise's production capacity is limited. In the face of many possible production targets and when the current production is limited and demands are uncertain, if an enterprise cannot produce everything on its own, then the enterprise must make trade-offs. Therefore, how to choose the production target that creates the biggest market niche and retains an enterprise's competitive edge hinges on the decision between self-production and outsourcing (including outsourcing processing and direct purchasing).

In an environment with uncertain demands, in terms of making outsourcing choices, Yeh (2008a) used triangular fuzzy numbers and trapezoidal fuzzy numbers to represent the holding costs, order costs and purchase costs in the no-stock-out model and used the center of gravity method to obtain the best ordering quantity. Chiu *et al*. (2009) used triangular fuzzy numbers to represent the ordering quantity of the no-stock-out model and used the approximative critical point and computer software to obtain the best ordering quantity. Taleizadeh *et al*. (2009) used triangular fuzzy numbers to represent the ordering quantity and the total required quantity in the no-stock-out model and used computer software to obtain the optimal solution. Jamalnia and Soukhakian (2009) used trapezoidal fuzzy numbers to represent the inventory costs in the no-stock-out model and used Fuzzy Nonlinear Programming (FNLP) and Fuzzy Geometric Programming (FGP) for the optimal solution. Grzegorzewski (2008) used trapezoidal fuzzy numbers to represent the ordering quantity, purchase costs, inventory costs, stock-out quantity, stock-out costs, demands and fixed costs in the stock-out allowed model and used the graded mean integration representation method to find the optimal solution.

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For the choice of self-production, Yeh (2008b) used triangular fuzzy numbers to represent demands, excess costs and stock-out costs. After defuzzification, one optimal solution can be obtained. Theodorou *et al*. (2007) used triangular fuzzy numbers to represent demands and prices and proposed four models to obtain the optimal solution. In a continuous review inventory model, Chiu *et al*. (2009) used triangular fuzzy numbers to represent ordering quantities, ordering costs, holding costs, shortage costs (varied or fixed), lead time, safety stock inventory and daily demands and proposed the mean value of a fuzzy number to obtain the optimal solution of the model. Regarding the unreliability of machines and the occurrence of defective items, Aharon *et al*. (2009) developed an algorithm for production and inventory control to let production systems meet the requirements. Blanchini *et al*. (2004); Bauso *et al*. (2006); Mohammadi *et al*. (2009) and Matondang and Jambak (2010) used the hedging point concept proposed by Kimemia and Gershwin to find out the optimal production control policy for a single product, that is, to find out the best hedging point, which is used to determine the optimal production rate.

Liao *et al*. (2009) conducted an investigation into the process of imperfect production and homogeneous reproduction. A production process is assumed to generate a portion of reproduced items, imperfective items and scrap. After scrap is discarded, the imperfective items are reproduced. The reproduction process is homogeneous producing finished products and scrap. They determined an optimal production lot size and proved that its profit function is a concave function. Chen and Khoo (2009) investigated a serial production system with random outputs and decided the best releasing amount of every production stage. In addition, Sarker *et al*. (2008) intended to quantify the influence of defective items in the system. The quantity of defective products is a random variable and has general discrete distributions. Goetz *et al*. (2008) generalized the transfer time of the Pavitsos and Kyriakidis (2009) model and derived the optimal cost limit.

The above shows that most of the studies investigate outsourcing or manufacturing separately; very few examine the decision between outsourcing and self-production. In the analysis of the choices of self-production and outsourcing, not all of the information relevant to decision making can be quantified. There also exist qualitative decision-making considerations, including business missions, business competition strategies and relationship maintenance between suppliers and customers. Cheshmberah *et al*. (2010) proposed a methodology of supply chain relationships, which provides an outsourcing decision basis for businesses; that is, businesses can measure and evaluate potential suppliers based on the importance of decision targets and purposes. Wu *et al*. (2010) proposed that AHP functions to systemize complex and nonstructural problems, to decompose high to low levels gradually and by quantified judgments, to simplify and improve decision-making procedures previously dependent on instinct, so as to obtain the weight values of various proposals and provide decision makers with sufficient information in choosing suitable proposals. A proposal with a larger weight value is more likely to be adopted, which reduces the risk of making a wrong decision.

The purpose of this study is to use the AHP to decide between self-production and outsourcing to derive a decision-making model. The researchers also weight the importance of the decision-making factors of production's comparative advantage and management, which can be the basis for deciding between self-production and outsourcing. The study framework is to be discussed in section 2. In the section 3, calculations of examples are given and discussed based on the results. Finally, the conclusion is formed in section 4 of this study.

MATERIALS AND METHODS

The assumptions of the model: The assumptions used in this model are as follows:

- Businesses own two or more self-produced products and the production capacity cannot satisfy the production demands of all self-produced products
- All of the self-produced products can be directly bought and obtained from the markets
- Decision-making considerations are compared based on comparative advantage

The model setup and application: The process framework of the study model is as shown in Fig. 1.

Step 1: Select and assess decision-making factors.

This study investigates outsourcing or self-production decision-making factors for businesses with limited production capacity. When businesses are making decisions, the selection of factors is relevant to the success or failure of the entire decision-making process. Under the assumption of comparative advantage, the model's decision-making factors are as shown in Fig. 2.

Cost comparison factors: In conducting the analysis of self-production or outsourcing costs, from the perspective of comparative advantage, opportunity costs are relevant to the analysis results.

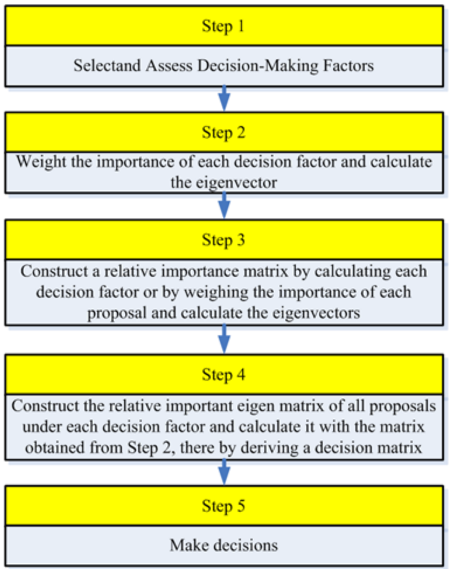

Fig. 1: The process framework of the model

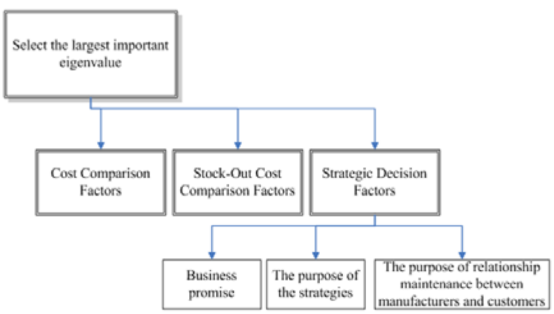

Fig. 2: The analysis hierarchy of the decision-making factors

Therefore, in comparing the self-production and outsourcing costs, one must select one choice and give up the opportunity cost of the other. The opportunity cost is included in the cost factor calculations, so that the advantages and disadvantages of various proposals can be comprehensively considered. Thus, the relationships of the decision-making influence factors are the following.

Outsourcing comparative costs = purchasing costs + incremental holding costs + ordering costs + transportation costs + idle capacity costs due to outsourcing. The equation is as follows:

$$C_B = C_b D + \frac{H_g}{2}(Q_B - \frac{p-d}{p}Q_P) + C_o\frac{D}{Q_B} + C_T\frac{D}{Q_B} + VQ_C \qquad (1)$$

Comparative costs of self-production = production costs + incremented raw material holding costs + setup costs + internal failure costs. Setup costs include the production setup costs, the setup cost of reproduction and the setup costs of machine maintenance; internal failure costs include correction costs, machine maintenance costs and waste costs. The equation is as follows:

$$C_P = C_p D + \frac{1}{2}H_m Q_P + \sum S_i \times \frac{D}{Q_P} + (C_r + M + R)\frac{D}{Q_P} \qquad (2)$$

Stock-out cost comparison factors: Stock-out may result from uncertain demands, imperfect products, or unreliable machines. Therefore, when conducting decision-making analyses, one must consider stock-out possible for both outsourcing and self-production and quantify it for analysis. The relationships of the decision-making influence factors are as follows.

Outsourcing stock-out comparative costs = {(average daily maximum demands - average daily demands) × purchasing lead time × probability + purchasing volume × average return rate}× stock-out cost per unit

The equation is as follows:

$$V_B = \{(d_{max} - d) \times LT_B \times P_v + r \times Q_B\} \times C_v \qquad (3)$$

Self-production stock-out comparative costs = {(average daily maximum demands - average daily demands) × production lead time × stock-out occurrence probability + average stock-out rate caused by defective items or machine malfunctioning in each production cycle × the production quantity of each production cycle × probability}× stock-out cost per unit:

$$V_P = \{(d_{max} - d) \times LT_P \times P_v + \sum r_i p_i \times Q_P\} \times C_v \qquad (4)$$

Strategic decision factors: Strategic decision factors are the decision factors that businesses must consider due to management or competing strategies, including business promise, the confidentiality of production technology, the purpose of applying competitive strategies and the purpose of maintaining relationships between suppliers and customers. When making decisions, the qualitative factors are included as decision factors and are given consideration.

Table 1: Comparison of the relative importance weights for decision factors

	Decision Factor 1	Decision Factor 2	Decision Factor 3
Decision Factor 1	1	C_{12}	C_{13}
Decision Factor 2	C_{21}	1	C_{23}
Decision Factor 3	C_{31}	C_{32}	1

Table 2: The comparison of relative importance weights at the ith decision factor for each proposal

Decision factor *i*	Proposal 1	Proposal 2	…..	Proposal k
Proposal 1	1	B^i_{12}	…..	B^i_{1k}
Proposal 2	B^i_{2k}	1	…..	B^i_{2k}
…..	…..	…..	…..	…..
Proposal k	B^i_{k1}	B^i_{k2}	…..	1

Step 2: Weight the importance of each decision factor and calculate the eigenvector.

AHP scale is divided into five items: equally important, more important, very important, extremely important and absolutely important. Each is also given a different value: 1, 3, 5, 7 and 9. Four other items that are in between the five basic items are given the value of 2, 4, 6 and 8. Accordingly, the researchers construct a relative importance matrix in relation to the decision factors. Its eigenvectors are calculated after standardization. The procedures are as follows:

- Construct a table of relative importance weights for decision factors, as indicated in Table 1
- where C_{ij} represents the importance level of the decision factor i compared to the decision factor j and $C_{ji} = 1 / C_{ij}$ is satisfied. At the same time, $C_{ij} = 1$ when i = j. For example, if the decision factor 2 is 5 times more important than the decision factor 3, then $C_{23} = 5$ and $C_{32} = 1/5$
- Calculate the eigenvectors of the matrix

Let the decision factor matrix $= A = \left[C_{ij}\right], 1 \le i, j \le 3$. Then, the eigenvectors satisfy the function: $AX = \lambda X$, where λ is a previously given specific value. The calculation is as follows:

Use the square algorithm for matrix A, that is, $A \otimes A = \left[a_{ij}\right], 1 \le i, j \le 3$, where $\otimes$ represents the product calculation of the matrix.

Add up each row of the obtained new matrix and standardize it to get the first eigenvector WA. That is, let $A_j = \sum_{i=1}^{3} a_{ij}, 1 \le i, j \le 3$ and standardize it to get, $w_j = A_j / \sum_{j=1}^{3} A_j$, which is $WA = \left[w_j\right]^T$.

Repeat Steps A and B until the difference between the obtained eigenvector and the former eigenvector is smaller than the previously given specific value λ. The result would be the desired value.

Step 3: Construct a relative importance matrix by calculating each decision factor or by weighing the importance of each proposal and calculate the eigenvectors

This study is concerned about the decision between self-production and outsourcing for the products. Therefore, for each product, there are two choices: self-production or outsourcing. For N products, there are 2^Noptions. The procedures are as follows:

- Construct a relative importance weight comparison table under each decision factor for each proposal, as shown in Table 2
- where B^i_{mn} represents proposal m's level of importance in relation to proposal n in consideration of decision factor i's influence over proposals and $B^i_{nm} = 1 / B^i_{mn}, 1 \le m, n \le k$ is satisfied
- Calculate the eigenvectors of the proposal matrix of each decision factor

Let the proposal matrix of the ith decision factor be $B^i = \left[B^i_{mn}\right], 1 \le m, n \le k$. As the procedure in Step 2, calculate the eigenvector WB^i_j of all proposals at each decision factor; i represents the ith decision factor and j represents the jth proposal.

Step 4: Construct the relative importance eigenmatrix of all proposals under each decision factor and calculate it with the matrix obtained from Step 2, thereby deriving a decision matrix.

Let $WB = \left[WB^1_j \quad WB^2_j \quad WB^3_j\right]$. Then, the decision matrix $D = WB \otimes WA$, where $\otimes$ represents the product calculation of the matrix.

Step 5: Make decisions.

The decision is based on the eigenvalue in the decision matrix (D). The proposal with the largest important eigenvalue is the priority choice.

RESULTS AND DISCUSSION

Company X is a manufacturer producing automatic mowers. Its major products are Type A and Type B mowers.

Table 3: Self-production and outsourcing costs and probability comparison table related to engines a and b

	D	d	d_{max}	P	Q_B	Q_P	C_b	C_p	H_g	H_m	C_o	C_r	M
a	8000	32	50	40	64	64	2000	1800	50	30	200	1000	5000
b	7500	30	40	38	67	55	2500	2200	60	30	200	8000	8000

Table 4: Self-production and outsourcing costs and probability comparison table related to engines a and b

	R	S_1	S_2	S_3	C_v	LT_B	LT_P	P_v	r	r_1	r_2	p_1	p_2	Q_C
a	1000	300	300	400	2500	3	1	0.1	0.15	0.1	0.2	0.2	0.25	2500
b	1500	500	500	400	3000	4	1	0.2	0.2	0.1	0.1	0.1	0.1	2000

Table 5: The relative importance weight comparison table of the decision factors

	Cost Comparison factor	Stock-out cost comparison factor	Strategic decision factor
Cost comparison factor	1	1/3	1/5
Stock-out cost comparison factor	3	1	3/5
Strategic decision factor	5	5/3	1

The main difference is that Type B mower has the extra "fuzzy" function. This technique is also an advantageous technique, highly protected by Company X. The main outputs of production are the blade control engines a and b. In the market, substitutes y and z can be found for the two types of engines. The past sales and production capacity data show that the total production capacity of the company is 10,000 machine hours/month. The production of engines a and b requires 8000 and 7500 machine hours, respectively. Also, the production cost (V) of every machine hour is 100. Other production-related data are as shown in Table 3-4.

Besides, when considering self-production and outsourcing choices, Company X also considers the product strategy developments of the company. Therefore, under the decision factor category, the influence factors of the strategy development needs, the relationship between the suppliers and customers and the enterprise mission are all considered at the same time. Based on the application of the above data, the calculation steps of study model are as follows.

Step 1: Select and assess the decision factors.

The decision factors of Company X include the cost comparison factor, stock-out cost comparison factor and strategic decision factor. Therein, the strategic decision factor includes the strategy development needs, the relationship between the suppliers and the customers and enterprise missions. The calculations of the related cost factors are as follows:

- The comparative costs obtained from outsourcing engine a, using Eq. 1 and $C_B(a)$ = \$16,402,830
- The comparative costs obtained from outsourcing engine b, using Eq. 1 and $C_B(b)$ = \$19,085,990
- The comparative costs obtained from the self-producing engine a, using Eq. 2 and $C_p(a)$ = \$15,775,960
- The comparative costs obtained from the self-producing engine b, using Eq. 2 and $C_p(b)$ = \$19,078,097
- The comparative costs obtained from outsourcing engine a, using Eq. 3 and $V_B(a)$ = \$45,000
- The comparative costs obtained from outsourcing engine b, using Eq. 3 and $V_B(b)$ = \$88,200
- The comparative costs obtained from self-producing engine a, using Eq. 4 and $V_P(a)$ = \$18,200
- The comparative costs obtained from self-producing engine b, using Eq. 4 and $V_P(b)$ = \$15,300

Step 2: Calculate the eigenvector based on the importance weights given to each decision factor.

Construct the relative importance weight comparison table of the decision factors.

For the product strategies and future developments of Company X, the relative importances of the three decision factors-the cost comparison factor, the stock-out cost comparison factor and the strategic decision factor-are as shown in Table 5.

Calculate the eigenvector WA.

Let:

$$A = \begin{bmatrix} 1 & 1/3 & 1/5 \\ 3 & 1 & 3/5 \\ 5 & 5/3 & 1 \end{bmatrix}$$

The calculations of the eigenvector are as follows:

- After calculating the square power of matrix A:

$$A = \begin{bmatrix} 3 & 1 & 0.6 \\ 9 & 3 & 1.8 \\ 15 & 5 & 3 \end{bmatrix}$$

Table 6: The relative importance weight comparison table of all proposals in relation to the cost comparison factor

Cost comparison factor	The outsourcing proposal of engine a	The self-production proposal of engine a	The outsourcing proposal of engine b	The self-production proposal of engine b
The outsourcing proposal of engine a	1	1/3	7	7
The self-production proposal of engine a	3	1	9	9
The outsourcing proposal of engine b	1/7	1/9	1	1
The self-production proposal of engine b	1/7	1/9	1	1

Table 7: The relative importance weight comparison table of all proposals in relation to the stock-out cost comparison factor

Stock-out cost comparison factor (B^2)	The outsourcing proposal of engine a	The self-production proposal of engine a	The outsourcing proposal of engine b	The self-production proposal of engine b
The outsourcing proposal of engine a	1	1/7	5	1/9
The self-production proposal of engine a	7	1	7	1/3
The outsourcing proposal of engine b	1/5	1/7	1	1/9
The self-production proposal of engine b	9	3	9	1

Table 8: The relative importance weight comparison table of all proposals in relation to the strategic decision factor

The strategic decision factor (B^3)	The outsourcing proposal of engine a	The self-production proposal of engine a	The outsourcing proposal of engine b	The self-production proposal of engine b
The outsourcing proposal of engine a	1	1/3	3	5
The self-production proposal of engine a	3	1	5	1/7
The outsourcing proposal of engine b	1/3	1/5	1	1/9
The self-production proposal of engine b	1/5	7	9	1

- After standardization, the eigenvector:

$$WA^1 = \begin{bmatrix} 0.11 \\ 0.33 \\ 0.56 \end{bmatrix}$$

- Repeat Procedure A. Then:

$$A = \begin{bmatrix} 27 & 9 & 5.4 \\ 81 & 27 & 16.2 \\ 135 & 45 & 27 \end{bmatrix}$$

- Repeat Procedure B. Then:

$$WA^2 = \begin{bmatrix} 0.11 \\ 0.33 \\ 0.56 \end{bmatrix}$$

- Calculate the difference between the two eigenvectors and see whether or not the difference is smaller than $\lambda = 0.01$. Then, the importance eigenvector of the decision factor:

$$WA = \begin{bmatrix} 0.11 \\ 0.33 \\ 0.56 \end{bmatrix}$$

Step 3: Construct a relative importance weight matrix by calculating each decision factor or by weighing the importance of each proposal and calculate the eigenvectors.

For Company X, the influence factor of the strategic decision factor for the relative importance weight matrix of self-producing and outsourcing engines a and b are as indicated in Table 6-8.

The calculation of the relative importance weight of the cost comparison factor is based on the comparative costs calculated according to Step 1. The ratios of all proposals are calculated. The relative importance weight corresponds to the value of the ratio, as shown in Table 6.

The calculation of the relative importance weight of the stock-out cost comparison factor is based on the comparative costs calculated according to Step 1. The ratios of all proposals are calculated. Based on the value of the ratio, the corresponding relative importance weights are as given in Table 7.

The relative importance weight of all proposals in relation to the strategic decision factor is evaluated by Company X and is indicated in Table 8.

Based on the calculation process of Step 2, the eigenvectors of each proposal at decision factors (B1, B2, B3) are $WB^1 = \begin{bmatrix} 0.30 \\ 0.60 \\ 0.05 \\ 0.05 \end{bmatrix}$, $WB^2 = \begin{bmatrix} 0.08 \\ 0.30 \\ 0.04 \\ 0.58 \end{bmatrix}$ and $WB^3 = \begin{bmatrix} 0.36 \\ 0.24 \\ 0.04 \\ 0.37 \end{bmatrix}$ respectively.

Step 4: Construct the relative importance eigenmatrix of all proposals under each decision factor and calculate it with the matrix obtained from Step 2, thereby deriving a decision matrix.

Let the relative importance matrix of the proposals in relation to the decision factors be:

$$WB = \begin{bmatrix} WB^1 & WB^2 & WB^3 \end{bmatrix} = \begin{bmatrix} 0.30 & 0.08 & 0.36 \\ 0.60 & 0.24 & 0.24 \\ 0.05 & 0.04 & 0.04 \\ 0.05 & 0.58 & 0.37 \end{bmatrix}$$

The decision matrix

$$D = WB \otimes WA = \begin{bmatrix} 0.30 & 0.08 & 0.36 \\ 0.60 & 0.24 & 0.24 \\ 0.05 & 0.04 & 0.04 \\ 0.05 & 0.58 & 0.37 \end{bmatrix} \otimes \begin{bmatrix} 0.11 \\ 0.33 \\ 0.56 \end{bmatrix} = \begin{bmatrix} 0.26 \\ 0.28 \\ 0.04 \\ 0.40 \end{bmatrix}$$

Step 5: Make decisions.

The decision between self-production and outsourcing is made based on choosing the proposal with the largest eigenvalue in the decision matrix. Therefore, the eigenvectors of the decision matrix obtained from Step 4 show that the self-production proposal of engine b has the greatest eigenvalue of 0.4, followed by the self-production proposal of engine a, the outsourcing proposal of engine a and finally, the outsourcing proposal of engine b. Therefore, for making the decisions between self-production and outsourcing, Company X should consider the following:

- Engine b should be entirely self-produced
- After producing engine b, use the rest of the production capacity to produce engine a
- If there is insufficiency in the production of engine a, then adopt the outsourcing proposal to make up for the insufficiency

CONCLUSION

Manufacturers cannot pursue a production economy of scale when they are faced with limited resources, restricted production capacity and HMLV production demand. Conversely, manufacturers must stand at the perspective of comparative advantage and rethink about the production and product strategies of the company. For different influences over the self-production and outsourcing choices, manufacturers need to severely control not only the costs for the pursuit of profits but also quality, which is the key to company success. The product quality needs to meet the customer demands. In terms of competition in time, the company also needs to satisfy the customer demand within a time frame, which is also the key to winning customers in the markets. Related strategy consideration factors also deeply affect companies deciding between self-production and outsourcing.

This study uses the AHP to derive a self-production and outsourcing decision-making model under limited production capacity. This model also takes into consideration the influence of quantitative and qualitative consideration factors on the company's decision making. Through weighting the importance of each decision factor and proposal by the company's decision maker based on their strategic needs and through eigenvector calculations, the company can obtain an optimal solution, faced with the two choices, based on model calculations. Also, based on the importance priority of each proposal in the decision matrix, the company can conduct production planning and devise purchasing plans. Hence, based on comparative advantage, the company can create the greatest profits and make full use of the existing production capacity scale to maximize the customer satisfaction level.

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