A study of equipment procurement scheme based on a multi-objective fuzzy optimization model

Meng Yang*, Huaiqiang Zhang, Weimin Ye
Naval University of Engineering, Wuhan, China
Email: 3189333780@qq.com*, zhanghq008@163.com, weimin_ye@126.com

***Abstract*—*Under the development trend of economic globalization, the development speed of network technology is getting faster and faster, the importance of enterprise procurement function is increasing, and procurement decision-making management has become the focus of enterprise leadership and management. In the face of increasingly fierce competition in the market environment, enterprises will use ways to reduce costs to improve the level of competition in the market. However, in the new market environment, choosing high-quality suppliers and implementing dynamic management to improve the level of competition is the key. After understanding the current situation of enterprise equipment procurement in the new era, this paper sorted out and analyzed the basic concepts of supply chain and procurement, clarified the importance of supplier selection in equipment* procurement, constructed a fuzzy weighted multi-objective optimization model and solution method under discount conditions, and conducted model verification analysis based on practical cases, to provide strong support for enterprise equipment procurement scheme design in the new era.**

Keywords—multi-objective fuzzy optimization model; Enterprise; Equipment procurement; Price discount

I. INTRODUCTION

With the trend of globalization of manufacturing industry, the connection between enterprises and suppliers is getting closer and closer. In this context, activities such as material acquisition, processing, assembly, and product sales will be carried out worldwide. The cost of the entire supply chain will occupy an increasing proportion of the total cost of the enterprise, and the importance of practical development is becoming more and more significant. Some scholars have proposed that the inventory costs of enterprises account for about 3% of sales, transportation costs account for about 3% of sales, and procurement costs account for about 40% to 60% of sales revenue. For the country, the public system accounts for more than 10% of the gross national product and involves more than 10% of the total labor force. Some scholars have also proposed that raw material procurement costs in developed countries account for about 40% to 60% of the unit cost of products, and the outsourcing cost of large automobile manufacturing enterprises accounts for more than 50% of sales. In comparison, suppliers cause 30% of quality problems and 80% of product delivery problems. It can be seen that scientific planning, reorganization, coordination, control and optimization of the public system of the enterprise can effectively control the cost and improve the economic benefits of the enterprise. However, from the perspective of practical development, most enterprises need to consume a lot of time and energy when controlling cost expenditure. They will focus on less than 40% of the enterprise management expenses, wages, and benefits, ignoring the importance of procurement cost management.[1.2]

In recent years, procurement has been highly valued by people, and procurement research has also become the focus of academic attention. Because of the close relationship between procurement and supplier selection, supplier selection must be considered first when studying the enterprise equipment procurement scheme. All procurement work should start from the selection of suppliers; the selection of suitable suppliers is the source of procurement business; supplier performance has a great impact on the procurement of enterprises in terms of delivery, product quality, and inventory equality, an impact on the success of procurement enterprises Reasonable selection of suppliers directly affects the enterprise to reduce costs and increase resilience. With the increasing importance of suppliers in the production management of enterprises, there is more and more research on supplier selection and equipment procurement quantity allocation. At present, many scholars at home and abroad have conducted in-depth research on it, put forward more valuable research topics, and published much professional literature. The research on this kind of problem is mainly reflected in two aspects: on the one hand, the research on the criterion of supplier selection, and the other hand, the research on the method of supplier selection. For example, some scholars put forward the mixed integer programming model of supplier selection and quantity determination, which comprehensively considers random demand. Some scholars put forward a non-cooperative negotiation strategy on supplier selection, which organically combines two multi-attribute analysis tools of multi-objective programming DEA to solve the supplier selection problem. Chinese scholars have also conducted experimental research on supplier selection and procurement quantity allocation for a long time and have obtained excellent results. For example, some scholars have constructed supplier selection criteria and discussed practical evaluation methods. Some scholars use activity-based costing to select and evaluate enterprises' suppliers. Some scholars have also proposed a hybrid model with AHP, DEA, and multi-objective programming as the core, and they have applied it in the decision-making of supplier selection and order quantity allocation. After integrating the research topics and main achievements of domestic and foreign scholars, this paper discusses the effectiveness and scientific value of equipment procurement schemes based on a multi-objective fuzzy optimization model to provide strong support for equipment procurement management of enterprises in the new era.[3.4]

II. METHODS

2.1 Model Assumptions

2.1. Participant assumptions

(1) Military: The first part of the equipment procurement contract aims to maximize the benefits generated by using equipment in the military.
(2) Contractors: The second part of the equipment procurement contract, based on the assumption of rational economic agents, aims to maximize their interests and knows the consequences of their actions. In addition, it is assumed that the contract signed between the military and the contractor is a fixed compensation plus incentive contract. [5]

2.2 Basic variable assumptions

(1) θ: Refers to external random factors, such as external environment, policies, etc., that are not controlled by both parties to the contract and θ follow a standard normal distribution with a mean δ^2 of 0 and a variance of.
(2) P : represents the final compensation paid by the military to the contractor.
(3) $c(m)$: represents the production effort cost of the contractor, m represents the level of production effort, the higher the m value, the harder the contractor's production is, which the military cannot observe. The marginal effort cost is increasing. This article assumes that b represents the coefficient of production effort cost $(b>0)$.
(4) $R(m)$: represents the contractor's output function $R(m)=am$, a represents the contractor's output coefficient $a \in (0,+\infty)$, assuming the contractor is of absolute risk avoidance type, ρ is a measure of absolute risk avoidance.
(5) φ : Represents the quality level of military products produced by the contractor. A comprehensive evaluation of the quality characteristics of the weapons and equipment determines the quality level of the contractor's military products. It can be calculated by weighting factors such as the high-tech content of the equipment, the degree of application of new materials and technologies, the stability, reliability, and support of the quality. This article θ assumes that the quality level $\varphi(m,\theta)$ is determined by the production effort level of the θ contractor m and external random variables m , which $\varphi(m,\theta)$ can be observed by both parties. It $\varphi(m,\theta)$ is θ a strictly increasing function, indicating that m under a certain external environment, the harder the contractor works, the higher the final quality of military products conforming to the law of diminishing marginal returns. It is a strictly decreasing function, indicating that under a certain level of production effort, the worse the external environment, the worse the quality of military products. This article assumes that the function takes a linear form $\varphi = m-\theta$.
(6) z : represents the difference z between the percentage of military production progress and the percentage of normal production progress m , $z>0$ indicating that the contractor's production progress is faster than normal progress, $z<0$ indicating that the contractor's production progress is slower than normal progress, $z=0$ indicating that the contractor's production progress is consistent with normal progress. Assuming it is related to the contractor's production effort level, the harder the contractor works, the faster the production progress will be, and it is θ also related z to external random variables (such as the deterioration of the international military environment, economic situation, or the impact of natural disasters, the production progress of military products may be affected to some extent).[6]
(7) $s(\varphi,z)$: The incentive contract adopted by the military for contractors is the final total compensation paid to the contractor, which consists of two parts: one is the total compensation paid by the military to the contractor, and the other is determined based on the military's direct observation of the quality of military products and the speed of production progress, $s(\varphi,z)$ that is, the p,φ,z function of. For the convenience of modeling and calculation, this article assumes a $s(\varphi,z)$ linear incentive contract, assuming $s(\varphi,z)=p+\alpha(\varphi+z)$ that α represents the incentive coefficient, which means that for $\varphi+z$ every unit increase, the contractor's compensation increases by α units.

Model Construction

Based on the above basic assumptions, the following text constructs the model.

The military's revenue function can be expressed as:

$$\begin{aligned} U_j &= am - p - \alpha(\varphi+z) \\ &= (a-\alpha)m - p - \alpha(z-\theta) \end{aligned} \quad (1)$$

The contractor's revenue function is:

$$U_c = p+\alpha(\varphi+z)-\frac{1}{2}bm^2-\frac{1}{2}\rho\alpha^2\delta^2 \quad (2)$$

If the retention income level of the contractor is $\overline{w}$ represented, then according to the theory of agency, the participation constraint IR of the contractor can be expressed as:

$$\text{IR: } p+\alpha(\varphi+z)-\frac{1}{2}bm^2-\frac{1}{2}\rho\alpha^2\delta^2 \geq \overline{w} \quad (3)$$

The incentive compatibility constraint IC can be expressed as:

$$\text{IC: } m \in \arg\max_{m}\{p+\alpha(\varphi+z)-\frac{1}{2}bm^2-\frac{1}{2}\rho\alpha^2\delta^2\} \quad (4)$$

By taking the first derivative of equation (4), we can obtain:

$$m=\frac{\alpha}{b} \quad (5)$$

Therefore, the standard proxy model expression can be summarized as:

$$
\begin{cases}
\max\limits_{\alpha} U_j = (a-\alpha)m - p - \alpha(z-\theta) \\
IR: p + \alpha(\varphi + z) - \frac{1}{2}bm^2 - \frac{1}{2}\rho\alpha^2\delta^2 \geq \overline{w} \text{ Using the} \\
IC: m = \frac{\alpha}{b}
\end{cases}
$$

C. ***Supply Chain***

The academic circle has not formed a unified definition of supply chain, and scholars mainly conduct in-depth analysis from different aspects. In the early stage, the supply chain, as the internal manufacturing process of manufacturing enterprises, refers to an internal process from procuring raw materials and parts through production transformation and sales activities and then transferring them to retailers and users. With the continuous expansion of the scope of the supply chain, it has formed a more systematic concept, which refers to the process of transforming raw materials into products through the manufacturing, assembly, distribution, retail and other processes of different enterprises in the chain, and then the transformation process to the end user. Chinese scholars believe that a good supply chain revolves around the core enterprise. After effective control of information flow, logistics and capital flow, it starts from purchasing raw materials, producing intermediate and final products, and sending the products to consumers through the sales network. In this process, suppliers, manufacturers and distributors will form an overall functional network chain structure model; the specific structure model is shown in Figure 1 below:[7]

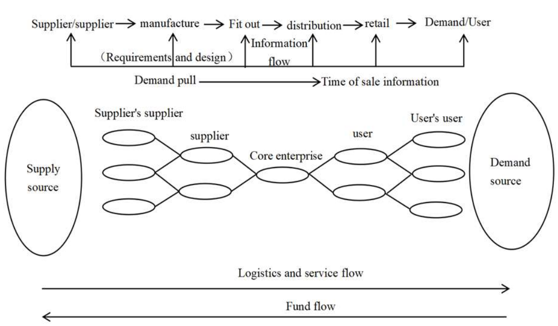

Figure 1. Structure model of supply chain

Fuzzy optimization theory and model analysis

Most practical decision problems usually contain multiple, incompatible objectives that must be considered simultaneously. As an extension of single-objective programming, multi-objective programming is defined as optimization into different objective functions under constraints. In essence, the basic principle of fuzzy optimization is to treat fuzzy targets and fuzzy constraints as fuzzy subsets on the solution set. Membership functions are usually used to represent the two fuzzy sets, and the intersection of fuzzy targets and fuzzy constraints is calculated and analyzed, so that the intersection membership function is maximized first, so as to obtain the optimal solution of the fuzzy optimization problem.

In the case of conflicting objective functions, there is usually no optimal solution, making all objective functions optimal at the same time. Under this condition, the concept of efficient solution is introduced, which means that the feasible solution of any objective function value cannot be improved without sacrificing other objective functions.[8.9]

Fuzzy information generally refers to some non-deterministic information that is not accurate, has no clear boundary, or is limited by human knowledge and cognition and cannot be expressed and clearly defined, and the system with fuzzy information is called a fuzzy system. The optimization method using precise mathematical theory can not accurately describe the behavior and characteristics of this kind of system, so it can not solve this kind of system effectively. As early as the 1950s, the rapidly developed fuzzy set theory and fuzzy optimization method provided the technical methods to deal with the modeling and optimization of such systems. The modeling and optimization method based on fuzzy set theory is also known as fuzzy modeling and fuzzy optimization method. There is an effective method to solve such problems, also known as symmetric multi-objective fuzzy programming model, which is shown as follows: In the above model, there are several fuzzy targets, and the specific solving process is as follows: First, the fuzzy targets are processed, and the membership function of each target is obtained; Secondly, the symmetric multi-objective fuzzy programming model is transformed to solve the problem, which is regarded as the equivalent single objective programming model. Finally, due to the contradiction of objectives in multi-objective planning, ensuring that each objective is as optimal as possible in practice is necessary.

2.3 Determine the weight coefficient

The equipment procurement scheme based on the multi-objective fuzzy optimization model mainly solves the decision-making problem of multiple products and multiple objectives. Considering that the suppliers attach different importance to each objective, determining the target weight will affect the realization of each objective and the final evaluation result. In general, objective-weighted AHP and fuzzy AHP methods can be used.

AHP, which first appeared in the 1970s, refers to a multi-objective decision-making method combining qualitative and quantitative analysis. Determining each indicator's weight is an important link in practical operation, and the determination process includes steps such as constructing a judgment matrix, weight calculation and compatibility judgment, as shown in Figure 2 below.[10,11]

The analytic hierarchy Process (AHP) determines the relative importance of each indicator through expert scoring. This step includes the scale determination to judge the importance of indicators and the construction of a judgment matrix according to expert scores. After comparing all the indicators, a judgment value is used to represent the relative importance. Common scaling methods include 1-5 scale method (minimum 1 point, maximum 5 points) and 1-9 scale method (minimum 1 point, maximum 9 points). In this case, the 1-9 scale method is used, and the values are described in Table 1:

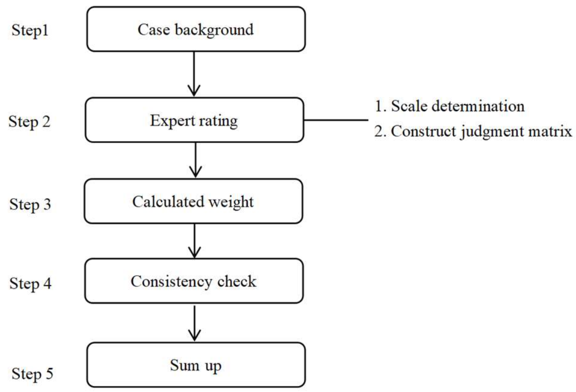

FIG. 2 Flowchart of AHP analysis

TABLE 1. SCALE METHOD

scale	Importance statement
1	Equally important
3	Row metrics are slightly more important than column metrics
5	Row indicators are more important than column indicators
7	Row indicators are very important to column indicators
9	Row metrics are absolutely important to column metrics
2,4,6,8	The above pairings determine the importance of the middle
Count backwards	If A is more important to B, mark 5 in row A and column B; When analyzing the importance of B to A, fill in 1/5

The fuzzy Analytic Hierarchy Process (F-AHP) is a method proposed by scholars unconsciously using fuzzy judgment when dealing with complex decision-making problems. The actual scale has gradually developed from the initial 1-9 scale to 9/9-1 scale and 10/10-18/2 scale. Various scales are introduced as shown in Table 2 below:

TABLE 2. VALUE ANALYSIS OF DIFFERENT SCALES

distinguish	Scale 1 to 9	Scale 9/9 to 9/1	Scale 10/10 to 18/2	Exponential scale
alike	1	9/9(1)	10/10(1)	9^0(1)
Slightly important	3	9/7(1.286)	12/8(1.50)	$9^{1/9}$(1.277)
Obvious importance	5	9/5(1.800)	14/6(2.333)	$9^{3/9}$(2.080)
Strongly important	7	9/3(3.000)	16/4(4)	$9^{6/9}$(4.327)
vital	9	9/1(9)	18/2(9)	$9^{9/9}$(9)
General formula	k	9/(10-k)	(9+k)/(11-k)	$9^{k/9}$

III. RESULTS

In this paper, after understanding the weighted fuzzy multi-objective programming model for multi-product purchase quantity allocation under the condition of price discount, a weighted fuzzy multi-objective programming model for solving such problems is constructed according to most of the previous literature research results, and experts determine the weight of each objective according to the actual situation. The fuzzy complementary judgment matrix is constructed using the 0.1 ~ 0.9 scale of F-AHP, as shown in Table 3 below. At the same time, according to the requirements and fuzzy consistency matrix, the planning analysis is carried out to clarify whether different target weights impact the results of procurement allocation. Suppose that an enterprise purchaser intends to purchase four kinds of products with six suppliers to choose from. After specifying the supplier's supply ability and service level, each product's supplier and its optimal purchase quota are calculated according to the above-given conditions. In the process of calculation and analysis, the quality, cost and delivery time are regarded as the objective function, and there is a certain conflict between the objectives to ensure that the degree of realization of each objective is within the predetermined range. The final results and schemes are satisfactory. The experimental results are shown in Table 4 below:[12]

Table 3 Scale analysis from 0.1 to 0.9

Scale 0 to 1	0.1~0.9 five scale	0.1~0.9 nine scales	implication
	0.1	0.1	It means element B is more important than element A
0		0.138	That means element B is strongly more important than element A
	0.3	0.325	It means element B is significantly more important than element A
		0.439	That means element B is slightly more important than element A
0.5	0.5	0.5	It means that element A is as important as element B
		0.561	It means element A is slightly more important than element B
k	0.7	0.675	Indicates that element A is significantly more important than element B
		0.862	Indicates that element A is strongly more important than element B
	0.9	0.9	It means element A is more important than element B

According to the analysis of the above table, under the three different weight conditions, some suppliers were eliminated, and some suppliers obtained orders in different degrees. This is because the eliminated supplier can only provide a certain product; the actual cost, product quality delivery time, and other indicators are significantly lower than other suppliers. The selected supplier has its competitive advantages in obtaining the purchase volume according to its advantages. From this analysis, it can be seen that under the condition of price discount, when selecting multi-product and multi-objective procurement, the final amount of equipment procurement obtained by all suppliers not only needs to consider the service capability and comprehensive level of

Table 4 Experimental results

w^1=(0.238,0.410,0.352)^r				w^2=(0.430,0.364,0.206)^r				w^3=(1/3,1/3,1/3)^r			
μ_1^1	μ_2^1	μ_3^1	$\sum_{l=1}^{3} w_1^1\,\mu_1^1$	μ_1^2	μ_2^2	μ_3^2	$\sum_{l=1}^{3} w_1^2\,\mu_1^2$	μ_1^3	μ_2^3	μ_3^3	$\sum_{l=1}^{3} w_1^3\,\mu_1^3$
0.837	0.813	0.714	0.794	0.961	0.695	0.644	0.782	0.897	0.707	0.684	0.763
x_{11}^o	x_{12}^o	x_{13}^o	x_{14}^o	x_{11}^o	x_{12}^o	x_{13}^o	x_{14}^o	x_{11}^o	x_{12}^o	x_{13}^o	x_{14}^o
3000	0	0	0	3000	0	0	0	3000	0	0	0
x_{21}^o	x_{22}^o	x_{23}^o	x_{24}^o	x_{21}^o	x_{22}^o	x_{23}^o	x_{24}^o	x_{21}^o	x_{22}^o	x_{23}^o	x_{24}^o
0	0	0	0	0	0	0	0	0	0	0	0
x_{31}^o	x_{32}^o	x_{33}^o	x_{34}^o	x_{31}^o	x_{32}^o	x_{33}^o	x_{34}^o	x_{31}^o	x_{32}^o	x_{33}^o	x_{34}^o
2800	0	4000	6000	2800	0	5000	6000	2800	0	4000	6000
x_{41}^o	x_{42}^o	x_{43}^o	x_{44}^o	x_{41}^o	x_{42}^o	x_{43}^o	x_{44}^o	x_{41}^o	x_{42}^o	x_{43}^o	x_{44}^o
0	800	0	0	0	800	0	0	0	800	0	0
x_{51}^o	x_{52}^o	x_{53}^o	x_{54}^o	x_{51}^o	x_{52}^o	x_{53}^o	x_{54}^o	x_{51}^o	x_{52}^o	x_{53}^o	x_{54}^o
0	5000	2000	0	0	5000	1000	0	0	5000	2000	0
x_{61}^o	x_{62}^o	x_{63}^o	x_{64}^o	x_{61}^o	x_{62}^o	x_{63}^o	x_{64}^o	x_{61}^o	x_{62}^o	x_{63}^o	x_{64}^o
0	0	0	400	0	0	0	400	0	0	0	400

suppliers but also needs to observe the different degrees of emphasis of suppliers on each objective. Enterprises' feasibility and scientific equipment procurement plan can be guaranteed only in this way.[13.14]

Conclusion

To sum up, the importance of procurement and supplier selection, based on the accumulated experience in equipment procurement management of existing enterprises, reasonable use of a multi-objective fuzzy optimization model to design equipment procurement scheme can not only ensure the normal operation of enterprise production but also reduce enterprise operating costs and obtain more economic benefits. [15, 16]

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