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# Parallel Optimization Method for Product Configuration and Supplier Selection Based On Interval

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**Abstract**. In order to realize the rapid product design and development under the uncertain environment, an optimization decision theory and method of product configuration and supplier selection based on interval information is proposed. This study proposes to combine the product configuration and supplier selection, consider multiple uncertain factors existing in the process of development, and express multiple uncertainties with interval numbers, establish an integrated optimization model for interval-based product configuration and supplier selection with product cost, delivery period and product performance as the objective function. By redefining the Pareto dominance relation of the objective function value as interval, the NSGA-Ⅱ algorithm is improved, and then a series of configuration options are obtained by directly solving the interval type integration model. Finally, the typical lathe products are used to verify the method.

## 1. Introduction

Product configuration is an effective way to achieve rapid product development. In the mass customization environment, through the product family based on the product configuration design, to mass production efficiency and cost to achieve the personalized product design and production, thereby enhancing the enterprise's rapid response capability and market competitiveness [1]. After the product configuration plan is determined, the enterprise will develop the product production plan and the purchased parts purchase plan according to the business strategy, and the choice of the best supplier for the purchased parts. The supplier selection is to select the optimal supplier from the multiple potential suppliers of the component according to the evaluation criteria [2]. Supplier selection as an important part of the procurement enterprise supply chain design, objective and reasonable choice of suppliers and with the best suppliers to establish long-term stable relations of cooperation can effectively reduce the risk and maximize the benefits of enterprises.

At present, domestic and foreign scholars have done a lot of research on product configuration and supplier selection, but the paper considering the integration of product configuration and supplier choice is rare. Jiang et al. [3] studied the inventory-driven product configuration optimization problem, established a multi-objective optimization model and solved the genetic algorithm. Yeh et al. [4] added the green criterion to the supplier selection criteria framework and established multi-objective mixed integer nonlinear and the multi-objective genetic algorithm is used to solve the problem. Lin et al. [5] proposed the fuzzy analysis network process of fuzzy multi-objective nonlinear programming to

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solve the problem of multi-criteria and inherent uncertainty in supplier selection. And so on. Luo et al. [6] established a unified optimization model for product family design and supplier selection to maximize the total income of the product family as the optimization goal and to use the genetic algorithm to solve the model.

According to the relevant literature, we can see that the process integration and parallel optimization between product configuration and supplier selection have not attracted much attention, and the research results are few. Further, due to the multiple uncertainties prevalent in the complex market environment, its impact on new product development cannot be ignored. To this end, this article for the actual process of product development, product configuration and supplier selection together, proposed in the form of interval to express the various aspects of the existence of uncertain information, and the establishment of product costs, delivery and product performance as the goal function of the interval of product configuration and supplier selection integrated optimization model, and NSGA-Ⅱ algorithm to redefine the dominant relationship, and then the interval-type integrated model for direct optimization.

## 2. Design of functional components of product family

Fully consider the uncertainty of product configuration and supplier selection in the process of establishing the integrated optimization model, analyzing the abstract design and mathematical modeling of the problem of the integrated design process shown in Figure 1. The set of functional components for the product family is $FM = \{FM_1, FM_2, \cdots, FM_n\}$, a functional component $FM_i$ can be implemented by several instance components $IM_i = \{IM_{i1}, IMi2, \cdots, IM_{im(i)}\}$, $m(i)$ as the number of instance components, $IM_{ij}(1 \le i \le n,\ 1 \le j \le m(i))$ represents the j-th instance component of the functional component. Therefore, the product configuration process can be expressed as follows: the function requirements of the customer are mapped to the function component set, and the target function set $FM^C = \{FM_1^C, FM_2^C, \cdots FM_w^C\}(w \le n)$ of the configured product is obtained. In the instance component corresponding to the target function component $IM_{ij}(1 \le i \le w,\ 1 \le j \le m(i))$ in the selection of an instance of the components, and ultimately constitute a configuration to meet customer needs products. When joining the supplier selection, the choice of instance components takes into account the differences between the attribute information of the instance components provided by different vendors. To this end, the product family configuration model and the supplier list are integrated to establish an integrated model, that is, on the basis of the product family configuration model for each instance component to increase the supplier list $S_{ijk}$, $S_{ijk}(1 \le i \le n, 1 \le j \le m(i), 1 \le k \le s(i,j))$ represents the k-th supplier of the j-th instance component $IM_{ij}$ of the functional component $FM_i$.

In order to solve the model effectively, the multiple uncertain information is expressed in the form of interval, and the integrated optimization model of product configuration and supplier selection based on interval is established.

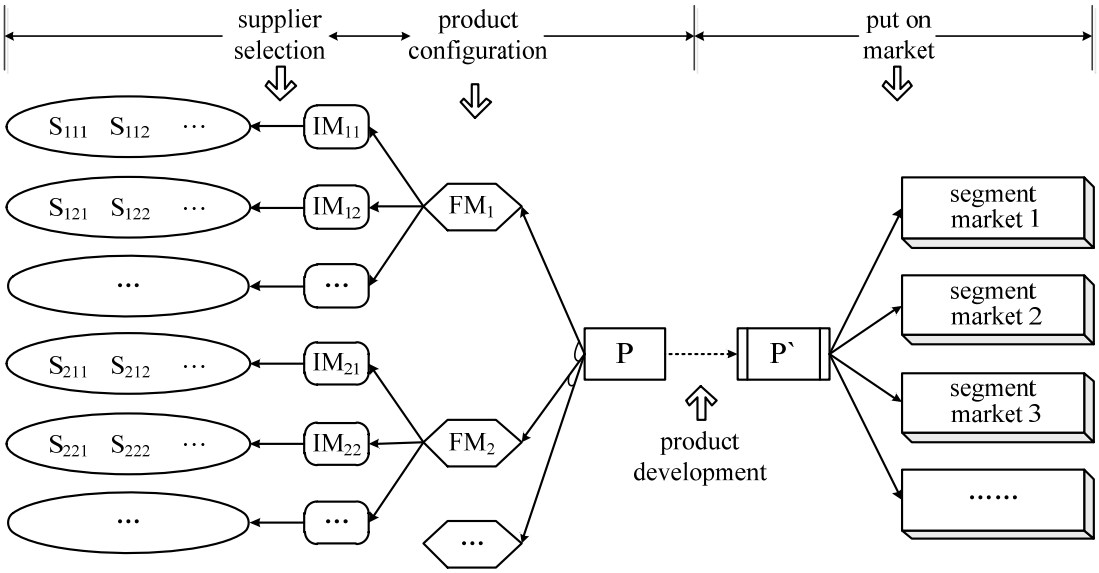



**Figure. 1** Product structure and supplier combination of parallel configuration process.

## 3. Establishment of interval multi-objective integrated optimization model

### *3.1. Integrated optimization model based on product cost*

The product family function component contains a set of mandatory components and an optional set of components. By building the cost matrix of the instance component, the mathematical model is constructed as follows:

$$\min C_z = \sum_{i=1}^{n} \sum_{j=1}^{m(i)} \sum_{k=1}^{s(i,j)} (\varepsilon_{ijk} \cdot c_{ijk}) + \left( \sum_{i=1}^{n} \sum_{j=1}^{m(i)} \sum_{k=1}^{s(i,j)} \varepsilon_{ijk} - 1 \right) \cdot C_A \tag{1}$$

$$(1+\alpha) \cdot C_z \le C_{\max}$$

Where, $C_z$ is the total cost range of the configured product $C_z = (\underline{C}_z, \overline{C}_z)$; $c_{ijk}$ represents the price range provided by the k-th supplier of the j-th instance component of the i-th functional set, $c_{ijk} = \left[ \underline{c}_{ijk}, \overline{c}_{ijk} \right]$; $\varepsilon_{ijk}$ represents a decision variable corresponding to the instance component $IM_{ij}$ and its supplier list $S_{ijk}$ ($1 \le k \le s(I, j)$): when $\varepsilon_{ijk}$=1, it indicates that the instance component $IM_{ij}$ participates in the configuration and corresponds to the supply merchant selected as $S_{ijk}$; When $\varepsilon_{ijk}$=0, it indicates that the instance component $IM_{ij}$ does not participate in the configuration, and the corresponding k-th vendor $S_{ijk}$ is not selected; for the function component $FM_i$, if $\sum_{j=1}^{m(i)} \sum_{k=1}^{s(i,j)} \varepsilon_{ijk} = 0$, the function component set is optional component set, and not involved in the configuration; for an instance component $IM_{ij}$, if $\sum_{k=1}^{s(i,j)} \varepsilon_{ijk} = 0$, then the instance component is not involved in the configuration. $C_A$ Is the average cost of assembly between modules, $C_A = [\underline{C}_A, \overline{C}_A]$; $\alpha$ is the average profit rate of the firm, $C_{\max}$ is the floating range of the customer budget price, $C_{\max} = (\underline{C}_{\max}, \overline{C}_{\max})$.

*3.2. Integrated optimization model based on product shipments*

In this paper, the total delivery time of the product does not take into account the response time of the supplier. By constructing the shipment matrix of the module instance, the product shipment period model is divided into two cases:

(1) Suppliers in parallel supply, that is, within a period of time suppliers at the same time supply, in which case the model is:

(2)

$$\min T_z = \left[ \max(T) + \left( \sum_{i=1}^{n} \sum_{j=1}^{m(i)} \sum_{k=1}^{s(i,j)} \varepsilon_{ijk} - 1 \right) T_A \right] \quad T_z \le T_{\max} \tag{2}$$

(3) Supplier serial supply, that is, suppliers in order of supply, in which case the model is:

(4)

$$\min T_z = \left[ \sum_{i=1}^{n} \sum_{j=1}^{m(i)} \sum_{k=1}^{s(i,j)} (\varepsilon_{ijk} t_{ijk}) + \left( \sum_{i=1}^{n} \sum_{j=1}^{m(i)} \sum_{k=1}^{s(i,j)} \varepsilon_{ijk} - 1 \right) T_A \right] \quad T_z \le T_{\max} \tag{3}$$

Where: $T_z = (\underline{T}_z, \overline{T}_z)$ is the total cost range of the configuration product; $t_{ijk}$ represents the cost range provided by the k-th vendor of the j-th instance component of the i-th functional set, $t_{ijk} = \left[ \underline{t}_{ijk}, \overline{t}_{ijk} \right]$; $T_A$ is the average assembly duration interval between modules, $T_A = [\underline{T}_A, \overline{T}_A]$; $T_{\max}$ is the maximum permissible shipping period for the customer, $T_{\max} = (\underline{T}_{\max}, \overline{T}_{\max})$.

*3.3. Integrated optimization model based on product performance*

The performance of the product includes both the functional and the quality of the product [10]. Let the product performance vector $P = (P_1, P_2, \mathrm{L}\ , P_D)^T$. Among them, $P_d$ is the $d$ performance of the product, $d = 1, 2, \mathrm{L}\ , D$, D is the number of products and the performance of the corresponding weight vector expressed as $\mathrm{W_P} = \left(\omega_1, \omega_2, \mathrm{L}\ , \omega_{\mathrm{D}}\right)^{\mathrm{T}}$. Using the previous method to build the product performance of the mathematical optimization model:

$$\max P_z = \sum_{i=1}^{n} \sum_{j=1}^{m(i)} \sum_{k=1}^{s(i,j)} \varepsilon_{ijk} \sum_{d=1}^{D} \omega_d \lambda_{ijk,d} \tag{4}$$

Where $P_z$ is the evaluation range of product performance, $P_z = [\underline{P}_z, \overline{P}_z]$, used to represent the comprehensive performance of the product, the greater the interval value, the better the performance of the product; $\lambda_{ijk,d} = [\underline{\lambda}_{ijk,d}, \overline{\lambda}_{ijk,d}]$ represents the k-th supplier of the j-th instance component of the i-th functional set and the relevance evaluation interval of the dth performance; $\varepsilon_{ijk}$ is the binary decision variable, and $\omega_d$ is the weight vector of the product performance set.

*3.4. The establishment of constraints*

(1) Price constraints

$$(1+\alpha)(\underline{C}_z, \overline{C}_z) \le (\underline{C}_{\max}, \overline{C}_{\max}) \tag{5}$$

(2) Time constraints

$$T_z \le T_{\max} \tag{6}$$

(3) Configuration constraints

$$\begin{cases} \sum_{k=1}^{s(i,j)} \varepsilon_{ijk} = 1, i = 1,2,\mathrm{L}\ ,n;\ j = 1,2,\mathrm{L}\ ,m(i) \\ \begin{cases} \sum_{j=1}^{m(i)} \sum_{k=1}^{s(i,j)} \varepsilon_{ijk} = 1 & \text{when } FM_i \text{ is an optional component set;} \\ \sum_{j=1}^{m(i)} \sum_{k=1}^{s(i,j)} \varepsilon_{ijk} \le 1 & \text{when } FM_i \text{ is a required component set.} \end{cases} \\ i = 1,2,\mathrm{L}\ ,n \end{cases} \tag{7}$$

## 4. The solution of three-interval uncertain multi-objectives optimization problem

*4.1. Problem description*

When the interval is used to describe the uncertainty problem, the general form of nonlinear interval uncertain multi-objective optimization problem can be expressed as [7]:

$$\begin{aligned} \min_x\ & f(\boldsymbol{x},\boldsymbol{a}) = \left\{ f_1(\boldsymbol{x},\boldsymbol{a}), f_2(\boldsymbol{x},\boldsymbol{a}),\mathrm{L}\ , f_k(\boldsymbol{x},\boldsymbol{a}) \right\} \\ \text{s.t.}\quad & g_j(\boldsymbol{x},\boldsymbol{a}) \le V_j = [\underline{V}_j, \overline{V}_j], \left( j = 1,2,\mathrm{L}\ ,m \right) \\ & h_k(\boldsymbol{x}) = B_k = [\underline{B}_k, \overline{B}_k], (k = 1,2,\mathrm{L}\ ,l) \\ & \boldsymbol{a} = (a_1, a_2,\mathrm{L}\ , a_q) \subset R^q, a_i = [\underline{a}_i, \overline{a}_i], \\ & \qquad i = 1,2,\mathrm{L}\ q; \\ & x_{il} \le x_i \le x_{iu}, (i = 1,2,\mathrm{L}\ ,n) \end{aligned} \tag{8}$$

Where $\boldsymbol{x}$ is the variable, $x_i$ is the decision vector, and, $x_{il}$ and $x_{iu}$ are the lower and upper limits of the design variables, respectively; $n$ is the number of optimization variables; $f(\boldsymbol{x},\boldsymbol{a})$ is the objective function vector, $f_k(\boldsymbol{x},\boldsymbol{a})$ is the k-th interval objective function; Vector $\boldsymbol{a}$ is $q$ dimension uncertainty, $a_i$ is the i-th variable of the interval vector, $\overline{a}_i$ and $\underline{a}_i$ are the upper and lower bounds of interval $a_i$ respectively; $g_j(\boldsymbol{x},\boldsymbol{a})$ is the j-th inequality of the constraint interval; $h_k(\boldsymbol{x})$ denotes the k-th constraint interval equation.

*4.2. Pareto dominance relation of genetic algorithm under interval*

The original NSGA-II algorithm is no longer applicable because it solves the multi-objective optimization problem of interval parameters. In this paper, the Pareto dominance relation of NSGA-II

algorithm is improved, and then the interval multi-objective optimization problem is solved directly. This method mainly compares the performance of different evolutionary individuals by defining the Pareto dominance relation of the objective function value as interval. This paper proposes a new genetic algorithm to solve the multi-objective optimization problem of interval parameter by replacing the traditional Pareto dominance relation and modifying the fast non-dominating ranking method of NSGA - II.

According to the literature [8], the dominant relationship based on interval confidence is adopted. Furthermore, since the objective function value is in the interval form, the crowding distance in the original NSGA-II algorithm is no longer applicable, and the new crowding distance based on the interval objective function needs to be redefined. The method of calculating the crowding distance mainly takes into account the volume of the objective function super-body and the degree of overlap of different super-bodies [8].

## 5. Example validation and analysis

### *5.1. Lathe product family of functional components set design and configuration optimization parameters to obtain*

This paper cites the data in [9] and modifies it. Taking the typical lathe product assembly of an enterprise as an example, the detailed list of main parts of the lathe is shown in Table 1. The unit cost of the module is $C_{\mathrm{A}} = [372,376]$ Yuan, the average assembly duration between modules is $T_A = [1.4,1.8]$ days, and the supplier is available in serial form.

Each supplier provides examples of the shipment interval and product price range shown in Table 1, in which modules 10 and module 11 for the optional module, the other is a mandatory module.

**Table. 1** design of functional components of lathe products

| Serial number | Module name | Instance number | Supplier name | Delivery period (d) | Price (Yuan) |
|---|---|---|---|---|---|
| 1 | Main force module | M11 | S111 | [36,40] | [15500,16800] |
| | | | S112 | [39,42] | [15000,16000] |
| | | M12 | S121 | [33,35] | [14500,15500] |
| | | | S122 | [29,31] | [17000,17800] |
| | | | S123 | [35,37] | [14800,15800] |
| | | M13 | S131 | [40,42] | [18000,19000] |
| | | | S132 | [38,40] | [18800,19800] |
| 2 | Horizontal and vertical feed module | M21 | S211 | [27,30] | [2600,3000] |
| | | | S212 | [26,28] | [3000,3200] |
| | | | S213 | [30,32] | [2450,2600] |
| | | M22 | S221 | [22,25] | [2500,2800] |
| | | | S222 | [25,27] | [2300,2550] |
| | | M23 | S231 | [23,25] | [3100,3400] |
| | | | S232 | [27,30] | [2800,3000] |
| … | … | … | … | … | … |
| 11 | Lighting module | M111 | S1111 | [1,2] | [80,100] |
| | | | S1112 | [2,3] | [75,90] |

Through the analysis of the performance of parts in the product family, the main performance of ordinary lathe is summarized. Select the main six items, namely: (1) movement smoothness; (2) noise; (3) accuracy; (4) life; (5) wear rate; (6) security. According to equation (6) to build the product family of functional modules corresponding to the supplier and the performance of the correlation matrix, as

shown in Table 2. The correlation values are described by interval, where strong, relatively strong, medium, weak, very weak, using interval values [8, 10], [6, 8], [4, 6], [2, 4], [0, 2]. Using the Analytic Hierarchy Process [10] to obtain the performance weight distribution is: $\omega_1$=0.2555, $\omega_2$=0.1462, $\omega_3$=0.2555, $\omega_4$=0.1462, $\omega_5$=0.0758, $\omega_6$=0.1214.

**Table. 2** Relevance matrix for suppliers and performance

| | P1 | P2 | P3 | P4 | P5 | P6 |
|---|---|---|---|---|---|---|
| S111 | [6,8] | [6,8] | [8,10] | [8,10] | [8,10] | [6,8] |
| S112 | [6,8] | [8,10] | [6,8] | [6,8] | [8,10] | [4,6] |
| S121 | [8,10] | [4,6] | [4,6] | [6,8] | [6,8] | [0,2] |
| S122 | [6,8] | [6,8] | [4,6] | [8,10] | [4,6] | [0,2] |
| … | … | … | … | … | … | … |
| S231 | [4,6] | [8,10] | [8,10] | [8,10] | [8,10] | [8,10] |
| S232 | [6,8] | [6,8] | [8,10] | [6,8] | [8,10] | [8,10] |
| … | … | … | … | … | … | … |
| S1111 | [2,4] | [6,8] | [0,2] | [6,8] | [0,2] | [4,6] |
| S1112 | [0,2] | [4,6] | [0,2] | [4,6] | [0,2] | [4,6] |

*5.2. Uncertain multi-target configuration optimization and supplier selection for lathe products*

Based on the method proposed in Section 2, the two-dimensional decision variable $\varepsilon_{ijk}$ is the design variable. The cost $C_z$ and the delivery time $T_z$ are the smallest, and the product performance $P_z$ is the target optimization function, which satisfies the formulas (3) and (4) under the conditions of product configuration optimization and supplier selection. According to the characteristics of NSGA-Ⅱ algorithm, the number of iterations $K=150$, the size of the configuration scheme group is $N=100$, the recombination probability $P_c=0.9$, the crossover probability $P_m=0.02$. Using Matlab to optimize and simulate the algorithm based on NSGA-Ⅱ, it should be noted that the improved NSGA-Ⅱ algorithm, which is suitable for interval, the Pareto set obtained here is no longer one (or more) hypersurfaces formed by multiple points, but there are a number of small super-form of one (or more) large super-body, so here Pareto set of images is difficult to intuitively given. According to the different needs of enterprises to determine the cost, shipping and product performance of the different focus in the optimization of the Pareto focus on the need to select the program, and find the corresponding design variable value, so as to get the most satisfied with the product configuration and supply Business options. According to the different requirements of the enterprise for the cost $C_z$, the shipping period $T_z$ and the product performance $P_z$, the three configuration options selected from the Pareto concentration are compared, as shown in Table 3.

**Table. 3** Optimal configuration scheme

| FiSerial number | Product configuration example | Supplier list | Cost C / Yuan | Delivery time T / d | Product performance P | Comprehensive evaluation |
|---|---|---|---|---|---|---|
| 1 | M12M21M31M41M51M61 M71M81M91 | S122S211S311S411S511S611S711S811S911 | [35120, 38010] | [130,152] | [43.82, 61.82] | low cost Short lead times Poor performance |
| 2 | M12M21M31M41M51M61 M73M81M92M101 | S123S211S311S411S511S611S732S811S923S1011 | [35852, 38966] | [141.4, 165.8] | [46.43, 66.43] | The cost is relatively low Long lead times Performance is better |
| 3 | M12M23M31M41M51M63 M71M82M91M101M111 | S122S232S311S411S511S631S711S811S912S1011S1112 | [36559, 39202] | [137.8, 163.6] | [49.38, 71.38] | The cost is relatively high Shorter lead times Performance is better |

## 6. Conclusion

On the basis of the pre-established product family structure, the multiple optimization factors of the development process are taken into account, and the integrated optimization model is selected for the interval product configuration and supplier selection with the product cost, the supply period and the product performance as the objective function. By redefining the Pareto dominance relation, the NSGA-Ⅱ algorithm is improved, and the interval-type integrated model is solved directly, and a series of configuration options are obtained. Through this study, we will help solve the parallel optimization problem of product configuration and supplier selection, and can effectively deal with the influence of multiple uncertain factors. This can play a certain role in promoting the basic research of product and supply chain optimization design in theory. In practice, it can provide scientific basis for the formulation of parallel decision-making of product design and supplier in complex market environment, and has important theoretical and practical value.

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