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Energy-Saving and Efficient Equipment Selection for Machining Process Based on Business Compass Model

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Abstract: The optimal selection of machine equipment can reduce the energy consumption and processing time of the parts processing process in enterprises. The energy consumption and time of using different equipment to process the same product vary greatly. Traditional equipment selection is only through qualitative analysis comparing the process characteristics of using different equipment or optimizing parameters for a single piece of equipment. It does not take into account the dynamics of the production process and does not consider the impact of process factors on production decisions. To solve this problem, we established a production equipment selection model based on the business compass model and proposed a calculation method that considered energy consumption and time objectives in the production process. Quantitative analysis can be performed for different equipment. The energy consumption and processing time of different equipment are calculated by the beetle antennae search (BAS) algorithm. A case study of machining end cap holes was carried out. The results showed that this method can calculate the optimal energy consumption and the optimal time of different equipment for producing the same product, which has good theoretical and practical significance for enterprises and governments to choose energy-saving and efficient production equipment.

Keywords: equipment selection decision; business compass; energy consumption; processing time; beetle antennae search algorithm

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1. Introduction

Industry plays a very important role in global economic development and has a huge impact on the development of various countries and regions [1]. Energy consumption in the industrial sector accounts for about 70% of the total energy consumption. Energy shortage and serious environmental pollution are the two major problems affecting economic growth and sustainable development [2]. The production model of high consumption, high pollution, and low profit in traditional industries is no longer suitable for the needs of social development. Modern manufacturing is changing to high-quality development and developing towards a green and sustainable direction [3,4]. The optimal selection of machine tool equipment is one of the effective ways to improve the greenness of the enterprise parts processing process. Under the condition that the production process requirements are met, there are often many options for machine tool equipment. The machining quality, time quota, cost, energy consumption, and noise pollution of different machine tools are different. Therefore, the selection of suitable processing equipment and processing technology is of great significance for enterprises to save energy and time [5–7].

Many scholars have studied the selection of processing technology. Liu et al. proposed a multi-objective optimization method for CNC machine tools that integrates the advantages of quality function deployment (QFD), fuzzy linear regression, and 0–1 objective planning. The engineering practicability of this method is verified by the case of the multi-objective decision-making problem of CNC machine tools in the process of building an intelligent manufacturing platform [8]. Zhou et al. proposed a machine tool selection method based on the combination of fuzzy analytic hierarchy process and entropy weight ideal point method and verified the method through the selection of machine tools for processing camshafts [9]. Li et al. established an evaluation model for machine tool equipment selection based on AHP and the ideal point method. The AHP was used to determine the weight of each influencing factor, and the selection model of machine tool equipment was evaluated by the ideal point method (TOPSIS). Combined with the selection of a batch of valve body and valve core stepped hole processing equipment in a factory, the feasibility and practicability of this method are illustrated [10]. Han et al. combined the entropy weight method with the TOPSIS method and established a decision-making model for the green process scheme of machining based on the entropy weight TOPSIS method. The feasibility and practicability of the model are verified by taking three machining process schemes of the lifting beam of the dump truck [11]. Zanuto et al. used a commercial life cycle assessment (LCA) tool to compare the environmental impact of different process operation strategies [12]. Klink et al. study grinding, EDM, laser machining, and milling manufacturing techniques, and different manufacturing processes are compared with each other with examples of machining mold cavities [13]. The era of Industry 4.0 will fundamentally change the production mode of the manufacturing industry, and the application of information technology in the manufacturing industry will be more extensive. Liu et al. proposed a digital twin-driven dynamic evaluation method for machining processes and verified it [14]. Chen et al. proposed an automated process planning approach for hybrid manufacturing processes, capable of automatically setting key parameters such as depth, tool accommodation, angle, and tool selection [15]. Komatsu proposed an automatic method for selecting machine tools by evaluating various machining processes and this method was validated [16]. Koremura et al. proposed a prediction method for process evaluation indicators using a computer-aided process planning (CAPP) system. By using these indicators, the operator can choose the most suitable one from the alternatives. A case study of process planning was carried out through bar machining, and the results showed the application value of the evaluation index [17]. The above literature proposed many methods for the selection of equipment in the production process, which effectively achieve the purpose. However, these methods used qualitative analysis when evaluating the equipment selection scheme, and the objectivity of the data cannot be well reflected.

To optimize machining parameters, Han et al. proposed a variable parameter drilling (VPD) method that can improve the machining efficiency and hole surface quality of porous parts and verified by a combined algorithm (CA) [18]. He et al. proposed an improved method to comprehensively optimize the distribution and parameters of machining allowance and conducted two case studies [19]. Wang et al. established a multi-objective optimization model of CNC turning process parameters based on the second-order regression equation of the response surface and used an improved artificial bee colony algorithm to solve the optimal parameter combination. The comparison with the results obtained by the NSGA-II algorithm showed the superiority of this method [20]. Li et al. constructed and validated the energy consumption and quality model of laser welding [21]. Jia et al. studied the power and energy consumption of the drilling process and established a mathematical model of energy consumption and verified the method through a hole machining case [22]. Xiao et al. proposed a CNC machining center process parameter optimization model that comprehensively considered energy consumption and cost, used a CA to solve the model, and verified the method by plane milling [23]. Ma et al. integrated CAD and CAM applications for virtual machining and process parameter optimization for complex end milling. The method was validated by machining an impeller [24]. Zhang et al. established an optimization model for the sequence of steps with the auxiliary processing time as the objective function and obtained the sequence of steps with the shortest auxiliary processing time through an improved genetic algorithm, which effectively reduced the processing time of parts [25]. The above literature optimized the process parameters of the machining process and compared and validated the data through quantitative analysis. However, these studies were performed on the same equipment and did not consider the effects of different processing equipment options.

There are many types of machine tools, and a certain processing feature of a product can often be realized by different machine tools. Under the condition that the production process requirements are met, the energy consumption and time of the processing process of different equipment vary greatly. The choice of machine tool equipment is a multi-objective and multi-scheme decision-making problem. In the actual design process, designers often rely on qualitative analysis to select processing equipment and cannot provide exact data support for equipment selection. Based on the business compass model, this paper established a production equipment selection model and analyzed the management process of enterprise equipment selection. A unified energy consumption and time objectives calculation model for different equipment was established, which was solved by the beetle antennae search algorithm. The method was verified by two kinds of equipment selection for processing a certain end cap hole, which can provide a reference for the efficient and energy-saving production of enterprises.

2. Production Equipment Selection Model Based on Business Compass Model

2.1. Business Compass Model

The business compass model is a new type of enterprise management and operation model, which organically integrates Chinese and Western management sciences, and summarizes a theoretical system with practical guiding significance from an innovative perspective. The "five dimensions" in the business compass not only come from the experience summary of business management theory but also the results of a large amount of practical research, which are closely related to the ancient Chinese "five elements" theory. A systematic view of Taoist philosophy in ancient China, the "five elements" theory is an important point of view [26–28]. The business compass model is shown in Figure 1. The "five dimensions" in the business compass are trend, path, skill, tool, and benefit, which provide a systematic view of business management. It is not only the five elements of business operations but also the five business capabilities that can introduce the production and operation of enterprises in detail.

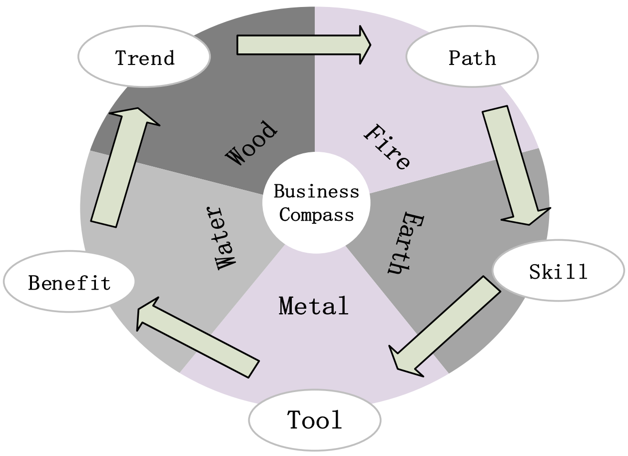

Figure 1. Business compass model.

The trend of the business compass is the environment in which an enterprise operates, including policies, industry prospects, and market demands. An enterprise's grasp of the "trend" often determines whether the enterprise can develop in the long term. The path of the business compass is the guiding ideology of enterprise management and the direction of enterprise development. The skill of the business compass is an enterprise's strategy, tactics, and strategic choice and layout, which determines the specific field in which the enterprise raises the technical threshold and defines the direction of technological innovation, product iteration, and service upgrade. The tool of the business compass is the product and technology of the enterprise, and it is the realization tool of the enterprise's production. The benefit of the business compass refers to the profit. The effective distribution of profit can fully mobilize the enthusiasm of the internal members of the enterprise and can also promote the enterprise to have a good growth environment [29].

2.2. Equipment Selection Model Based on Business Compass

There are often a variety of machine tools that can be selected for processing the same product, The energy consumption and cost of different equipment vary greatly. Choosing the right processing equipment is of great significance for the high efficiency and energy saving of enterprises. As the guiding concept of enterprise management, the business compass can provide guidance for the selection of equipment for processing the same product. The business compass can provide guidance on enterprise equipment selection. "Trend" is the environment in which enterprises make equipment selection. In recent years, the manufacturing industry has been developing in the direction of low-carbon manufacturing and green manufacturing, and enterprise production should keep up with the development trend. "Path" is the purpose of equipment selection. The goal of an enterprise is to produce products, and equipment alternatives should be selected according to product characteristics. "Skill" is how to choose the appropriate production equipment, which needs to be judged according to the product and the current technical level. "Tool" is the production equipment, and the performance, parameters, and processing links of the equipment must be considered. "Benefit" is the profit of the product and what equipment to choose can make the profit of the product the highest. This article summarized the model of enterprise production equipment selection based on the model of the business compass, as shown in Figure 2. This model takes the production and operation of the enterprise as the core. The management concept of the business compass guides the management and operation of the enterprise. The operation department is responsible for the management of the production conditions and technological innovation of the enterprise. The designer initially selects several suitable schemes according to the production conditions of the enterprise and the characteristics of the workpiece to be processed, conducts a comprehensive evaluation of the schemes, and then selects the most suitable production equipment. It can be seen from this that the model has good industrial applicability when selecting equipment for the production of the same product and can help enterprises select suitable processing equipment. The selection of equipment can help enterprises to produce with high efficiency and energy saving, and enterprises can obtain more profit space and promote enterprise development.

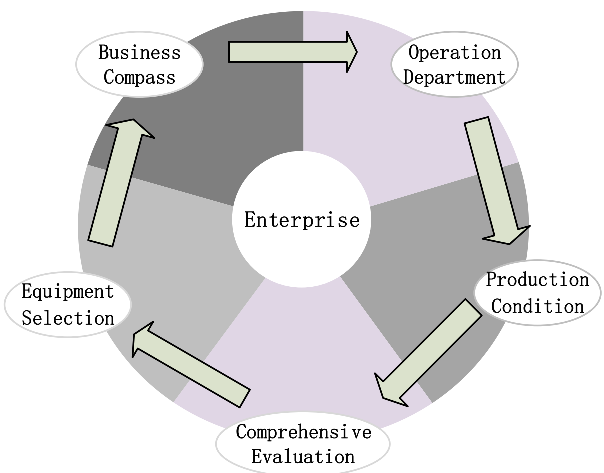

Figure 2. Production equipment selection model.

3. Multi-Objective Unified Computing Model for Different Equipment

The industrial industry pays great attention to the economy of the production process. By optimizing the energy and time objectives of product processing, the optimal energy consumption and time of the production process can be obtained, thereby reducing the investment of resources and promoting the rational use of resources. Energy cost and worker time cost are important components of the total cost. Reducing energy consumption and processing time can also reduce production costs and increase profits. Many types of equipment can be used to produce the same product, and it is important to choose the right one. The establishment of a uniform energy consumption and time objective function model is the basis of equipment selection. The unified energy consumption and time model has better engineering applicability. The calculation process of energy consumption and time is as follows [30–33].

3.1. Energy Consumption Objective

According to the state of the machine tool in the working process, the energy consumption of the machining process can be divided into standby energy consumption E_f, no-load energy consumption E_{air}, actual cutting energy consumption E_c, and additional load energy consumption E_a. During the cutting process, the state of the machine tool has little effect on the energy consumption of the auxiliary systems, such as lighting systems, cooling fans, and lubrication systems, and its power is only related to its own characteristics. The energy consumption calculation process is as follows.

The power of the machine tool with no load Is related to the spindle speed, and the expression is as follows:

$$P_{air} = An^2 + Bn + C \tag{1}$$

where coefficients A, B, C can be obtained by fitting the measured data, P_{air} is the no-load power, and n is the spindle speed.

The no-load energy consumption is

$$E_{air} = (An^2 + Bn + C) \times t_{air} \tag{2}$$

where E_{air} is no-load energy consumption, and t_{air} is machine no-load time.

The actual cutting energy consumption E_c is,

$$E_c = P_c t_c = F_c v_c t_c \tag{3}$$

P_c is the cutting power for machine tool, t_c is cutting time, F_c is cutting force, and v_c is cutting speed.

The milling process of machine tools is accompanied by additional load loss, and the additional loss mechanism is very complicated. It is generally believed that the loss of energy of the additional load is approximately proportional to the cutting energy consumption.

$$E_a = bE_c \tag{4}$$

where b is the correlation coefficient, generally between 0.15 and 0.25.

The energy consumption of the cutting process is

$$E = E_f + E_{air} + E_c + E_a = P_f t_f + (An^2 + Bn + C)t_{air} + (1 + b)F_c v_c t_c \tag{5}$$

where P_f, t_f are the standby power and standby time of the machine tool, respectively; A, B, C are coefficients related to no-load power consumption; n is the spindle speed, t_{air} is machine no-load time; b is the correlation coefficient; and F_c, v_c, t_c are the cutting force, cutting speed, and cutting time, respectively.

3.2. Time Objective

The total time T of the workpiece cutting process mainly includes: standby time t_f, no load time t_{air}, and actual cutting time t_c. The total time T of the cutting process is calculated as follows:

$$T = t_f + t_c + t_{air} \tag{6}$$

$$t_c = \frac{60L}{nf} \tag{7}$$

where L is the total length of the toolpath during the machining process, n is the spindle speed of the machine tool, and f is the feed rate during the machining process.

3.3. Constraints

The value of the objective function must meet the machining cutting parameters and quality requirements, and the relevant constraints are such as Formulas (8)–(13).

$$n_{\min} \leq n \leq n_{\max} \tag{8}$$

where $n_{\min}$ is the minimum spindle, and $n_{\max}$ is the maximum spindle speed.

$$f_{\min} \leq f \leq f_{\max} \tag{9}$$

where $f_{\min}$ is the lowest feed rate, and $f_{\max}$ is the fastest feed rate.

$$P_c \leq \eta P_{\max} \tag{10}$$

where $P_{\max}$ is the machine maximum power, and η is the effective coefficient of machine power

$$F \leq F_{\max} \tag{11}$$

where $F_{\max}$ is the maximum cutting force.

$$T_{\min} \leq T \leq T_{\max} \tag{12}$$

where $T_{\min}$ is the tool life lower limit, and $T_{\max}$ is the tool life upper limit.

$$R \leq R_{\max} \tag{13}$$

where $R_{\max}$ is the maximum allowable surface roughness.

4. Beetle Antennae Search Algorithm

4.1. Analysis of Beetle Antenna Search Algorithm

The BAS algorithm was proposed by Jiang et al. in 2017 [34]. The BAS algorithm was proposed based on the foraging behavior of beetles. In the process of beetle foraging, it uses its left and right antennas to detect the food taste concentration. If the food taste concentration detected by the left antenna is greater, it will move to the left; otherwise, it will move to the right. During the whole process of moving, its position is constantly adjusted and changed until it moves to the position of the food. Different from many multi-swarm heuristic algorithms, the BAS algorithm requires only one beetle; therefore, its operation is simple, the amount of calculation is less, and the iteration speed is faster [35,36].

4.2. Beetle Antenna Search Algorithm Flow

The flowchart of the BAS algorithm is shown in Figure 3. The following are the specific steps [37]:

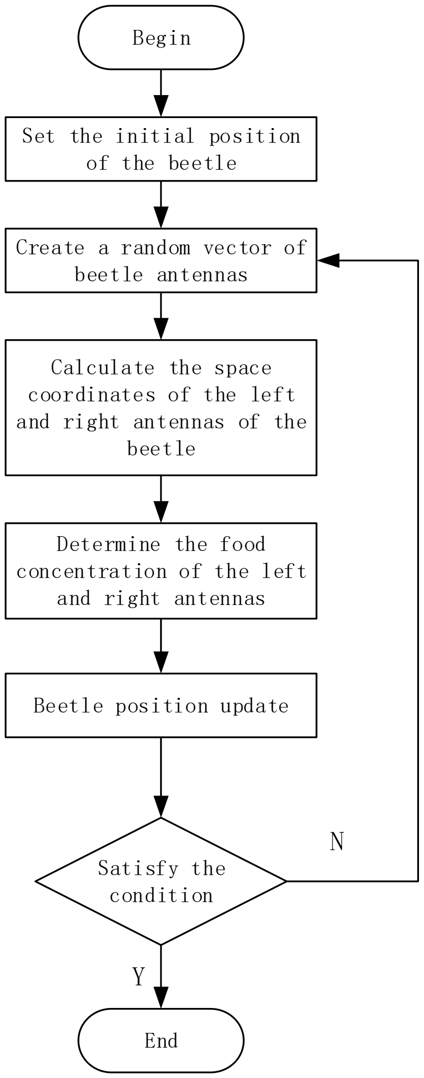

Figure 3. BAS algorithm flow.

1. For an n-dimensional optimization problem, record the centroid of the beetle as $x(x_1, x_2, \cdots, x_n)$; then, the fitness function can be expressed as $f(x_1, x_2, \cdots, x_n)$. Before the beetle searches for food, its initial position needs to be set, that is, the initial value of x.
2. Since the direction of the beetle search is random, it is necessary to establish a random vector of beetles and normalize it.

$$V = \frac{rands(n,1)}{||rands(n,1)||} \tag{14}$$

where $rands(n,1)$ is a randomly generated n-dimensional vector between 0 and 1. At this time, the beetle's left antenna coordinate x_l and right antenna coordinate x_r can be obtained as:

$$x_l = x + d \times V \tag{15}$$

$$x_r = x - d \times V \tag{16}$$

where d is the distance between the antenna of left and right.

3. Compare the food taste concentration and fitness value of the left antenna and the right antenna of beetles.

When $f(x_l) < f(x_r)$, then:

$$x_k = x_{k-1} + step \times \frac{x_l - x_r}{||x_l - x_r||} \tag{17}$$

When $f(x_l) \geq f(x_r)$, then:

$$x_k = x_{k-1} - step \times \frac{x_l - x_r}{||x_l - x_r||} \tag{18}$$

In the above two formulas, *step* represents the moving step of the beetle, and x_k and x_{k-1} represent the value of x at the k and $k-1$ iterations, respectively.

4. Enter the iterative process. When the maximum number of iterations is reached or the fitness value meets the requirements, the iteration stops and the result is output, which is the optimal value at this time.

The algorithm runs on MATLAB 2016b. The dimension n is 2, the initial step size of the beetle *step* is 0.3, the distance between the two whiskers of the beetle d is 2, and the number of iterations is 300.

5. Case Study

An enterprise needs to process a batch of end caps. The size of the workpiece to be processed is shown in Figure 4. The material is Q235, and the thickness is 20 mm, with 100,000 pieces produced. Now, it is necessary to process four holes on the end cap. Available equipment is a lathe and a drill.

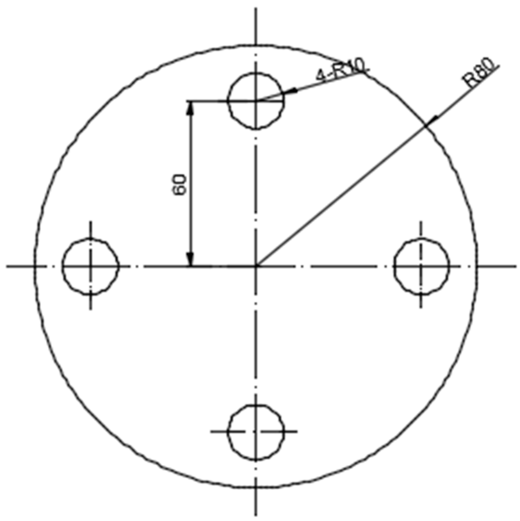

Figure 4. Workpiece dimensions.

5.1. Analysis of Available Equipment Conditions

The company currently has two types of equipment for processing this part, namely, a lathe and a drilling machine. Tables 1–3 show the main parameters of the lathe. Table 1 shows the lathe parameters, Table 2 shows the range of the lathe cutting parameters, and Table 3 shows the relevant parameters of the turning experience model.

Table 1. Lathe parameters.

Model	Spindle Motor Power/kw	Low Gear Speed Regulation Range/(r·min^{-1})	High Gear Speed Regulation Range/(r·min^{-1})
C2-6136HK/1	5.5	100–1000	300–2100

Table 2. Selection range of cutting parameters.

Cutting Parameters	Value Range
$f/(\mathrm{mm}\cdot\mathrm{r}^{-1})$	$0.05-0.3$
a_p/mm	0.5–4
$n/(\mathrm{r}\cdot\mathrm{min}^{-1})$	$50-1000$

Table 3. Turning empirical model parameters.

C_{Fc}	x_{Fc}	y_{Fc}	n_{Fc}	k_{Fc}
2795	1	0.75	−0.15	0.778

The model of the drilling machine is the ZXK50 CNC vertical drilling machine. Table 4 shows the relevant parameters of the drilling machine, and Table 5 shows the parameters of the drill bit.

Table 4. Drilling Machine Parameters.

Machine Rated Power p/kw	Spindle Speed Range (r/min)	Feed Speed Range (mm/min)	Machine Efficiency η
3.7	45–2000	20–600	0.8

Table 5. Drill Bit Parameters.

Number of Cutting Edges	Material	Economic Life/*min*
2	YG8	50

5.2. Optimization Results

The application process of the BAS algorithm in the end cap processing includes the following steps:

1. Establish a fitness function according to the energy consumption and time models of the production processes of different equipment.
2. Determine the random vector of beetles. The dimension n is 2, the initial step size of the beetle $step$ is 0.3, the distance between the two whiskers of the beetle d is 2, and the number of iterations is 300.
3. The coordinates of the left and right antennas of the beetle are calculated, and the corresponding fitness values are calculated.
4. Update the location of beetles.
5. Determine whether the number of iterations is satisfied and output the result if it is satisfied. If not, go back to Step 2.

The optimal energy consumption and processing time of different equipment when processing the same product can be obtained through the BAS algorithm. Figure 5 shows the energy consumption and iteration times of lathe processing, and Figure 6 shows the energy consumption and iteration times of drilling machine processing. Figures 7 and 8 separately show the time and iteration times of lathe and drilling processing. Through the optimization calculation, the optimal objectives when different equipment process the same product can be obtained.

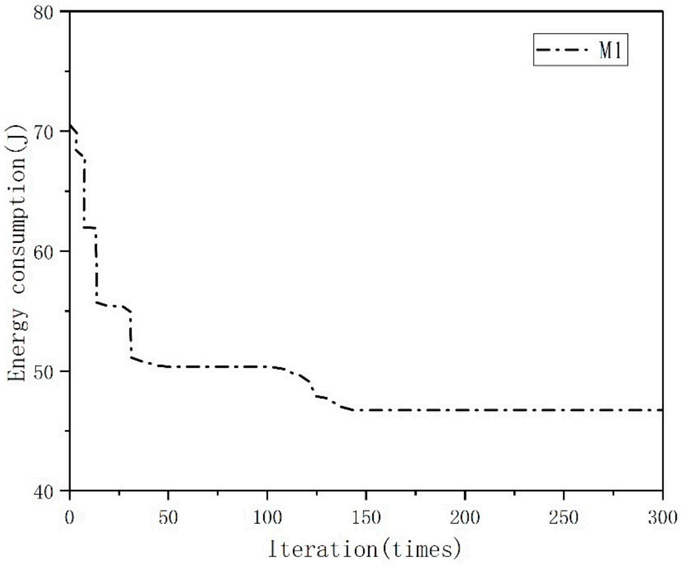

Figure 5. Energy consumption iterative curve of lathe.

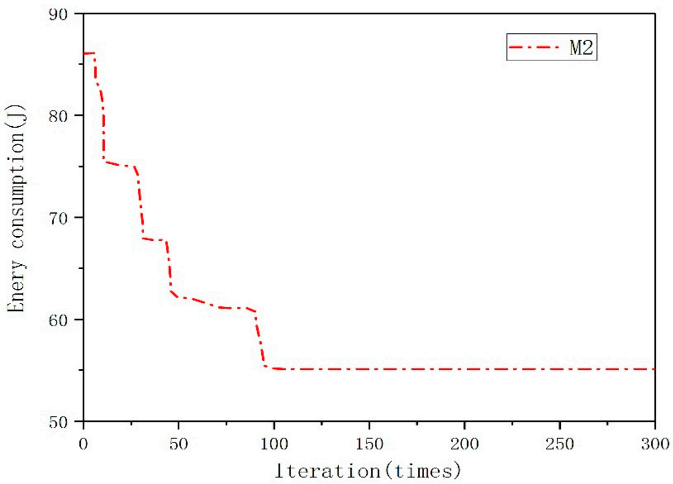

Figure 6. Energy consumption iterative curve of drilling machine.

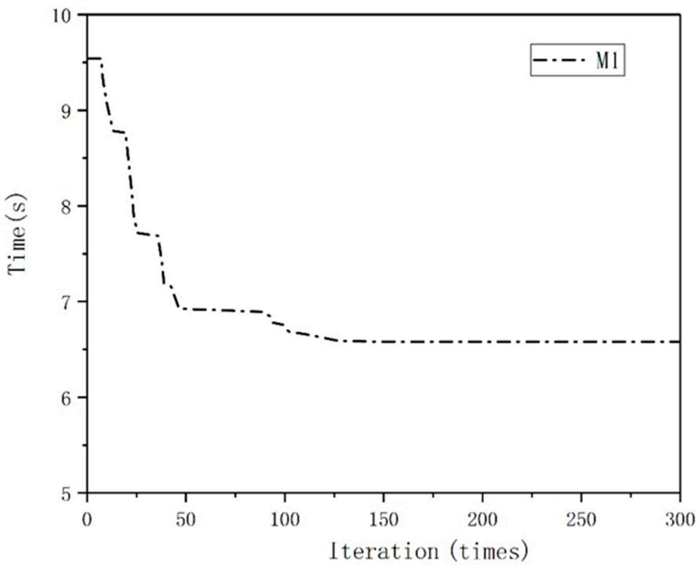

Figure 7. Time iterative curve of lathe.

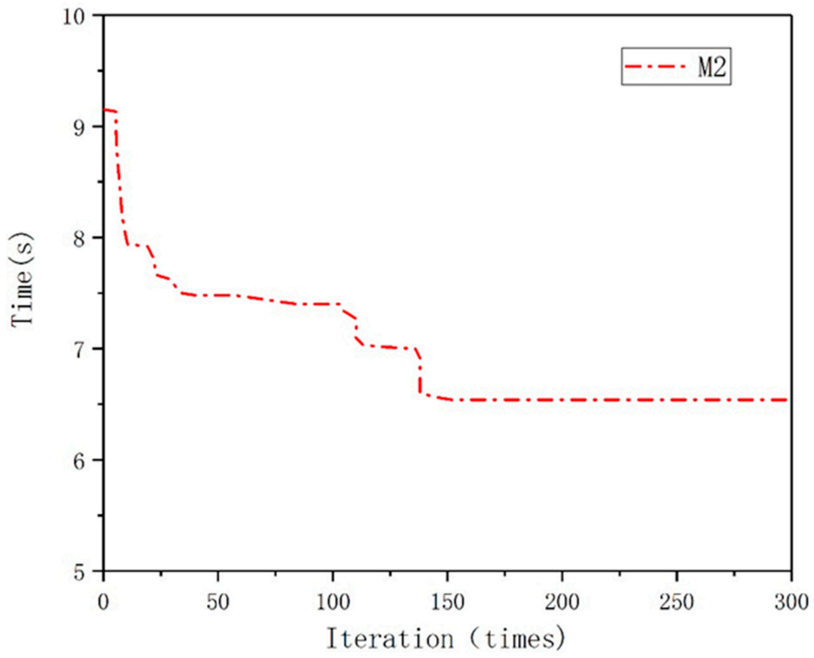

Figure 8. Time iterative curve of drilling machine.

5.3. Results and Discussion

5.3.1. Comparison

The optimization results of processing the same product with different equipment are shown in Table 6. As can be seen from the table, the energy consumption of lathe processing is reduced by 15.2%, and the processing time is reduced by 0.61% compared with drilling machine processing. Less energy and time are used when machining this part with a lathe, so a lathe is chosen as the machining equipment. The optimal values of energy consumption and time are 46.73 and 6.54, respectively. This method improves the profit of the enterprise by choosing a way of less energy consumption and processing time.

Table 6. Comparison of Different Equipment Optimization Results.

Equipment	Energy Consumption	Time
Lathe	46.73	6.54
Drilling machine	55.12	6.58

5.3.2. Compared with Previous Works

In order to achieve energy-saving and high efficiency in the production process, scholars at home and abroad have studied some equipment selection optimization methods and algorithms and have effectively achieved the goal. However, there are also some problems. The comparison between the traditional equipment selection method and the method proposed in this paper is shown in Figure 9. The calculation of different schemes in [8–17] was static, and only qualitative analysis was carried out for different equipment. Qualitative analysis in the new era is difficult for enterprises to make the appropriate choice based on the actual situation. Refs. [18–25] carried out parameter optimization for the same equipment without considering the influence of different processing equipment for the same product. In [22], Jia et al. proposed a method for obtaining and saving power and energy consumption during drilling and established a mathematical model of energy consumption. The method is verified by a case of hole machining, and the optimal energy consumption is obtained. If the turning method is used, the energy consumption can be reduced by more than 5%.

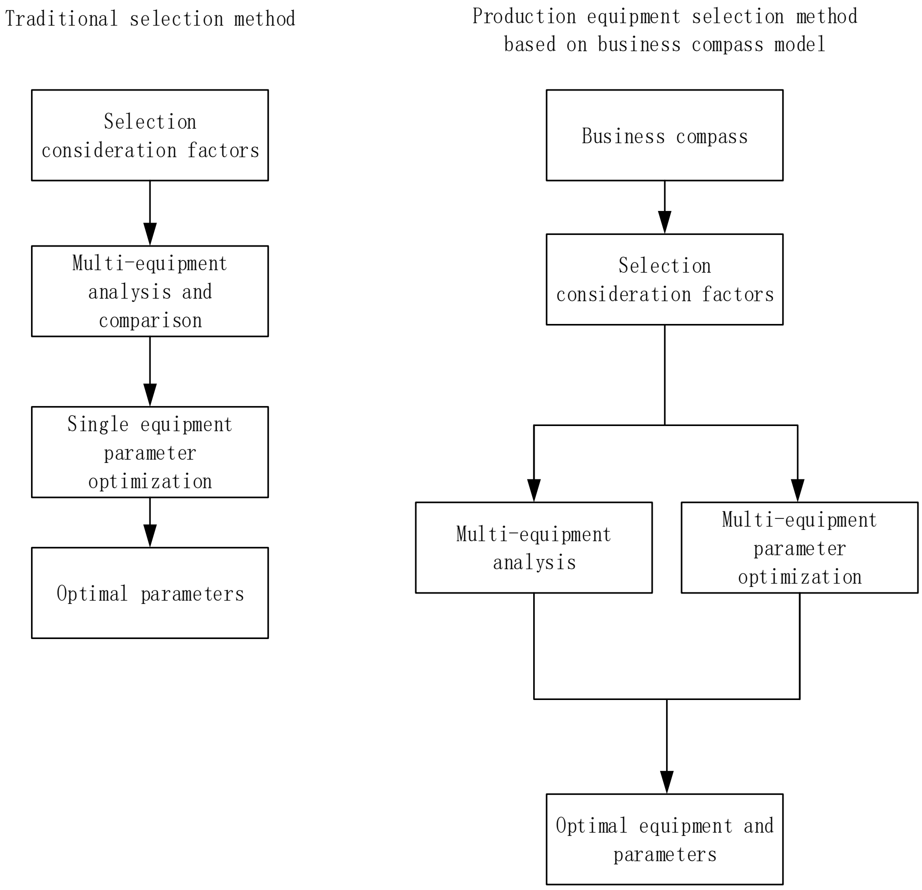

Figure 9. Comparison between traditional equipment selection method and production equipment selection method based on business compass.

Based on the model of the business compass, this article combined enterprise management with production equipment selection and established a production equipment selection model. The unified energy consumption and time model of different equipment were established and used the beetle search algorithm to calculate. Compared with other algorithms, the beetle antennae search algorithm only needs one body, and the amount of computation is greatly reduced. It is simple in principle, uses fewer parameters, requires less computation, and is faster to solve. The result proves the necessity and significance of the method.

5.4. Practical Implications and Future Steps

This article proposed an equipment selection model based on the business compass, and a unified calculation method for energy consumption and time of different devices, which was verified by an example. This research can help enterprises choose the best production equipment and provide a reference for energy-saving and efficient production of enterprises. However, this article only considers the comparison of different equipment for processing the same product. In the future, the influence of workshop workers, equipment status, material information, and other factors on the equipment selection will be analyzed.

6. Conclusions

Equipment selection is an important part of product production decision-making and is of great significance to product production and operation management. Choosing the right production equipment can save resources, improve production efficiency, help the planning and implementation of production and operation management activities, and promote the realization of efficient, flexible, punctual, and clean production and operation management goals. The selection of production equipment is a complex issue, which can promote the sustainable development of society. Based on the enterprise management model of the business compass, this article established a model of enterprise production equipment selection and proposed a unified method to calculate the energy consumption and processing time of various equipment. This model can help enterprises to produce energy-saving and efficient production.

1. Based on the model of the business compass, this article established a model of enterprise production equipment selection. This model combines enterprise operation management with production equipment selection and analyzes the enterprise management process to realize equipment selection.
2. A unified energy consumption and time calculation model to produce the same product with multiple equipment was established and the model was verified by the case of machining end cap holes.
3. The BAS algorithm was used to optimize and calculate the energy consumption and time of multiple equipment processing.

The research result showed that this method can quantitatively analyze the energy consumption and time when different equipment processes the same product. It has important significance for enterprise production. From the perspective of enterprise management, a method for selecting production equipment is proposed, which can provide guidance for enterprises to choose energy-saving and efficient equipment during production and can also provide advice for the government to save energy. However, in this paper, only the energy consumption and processing time of the production process were studied. More optimization objectives such as the economy and carbon emission will be considered in the future. This paper only considers the comparison of different equipment for processing the same product and will analyze the influence of workshop workers, equipment status, materials, and other factors on equipment selection in the future.

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References

1. Zhu, Q.; Li, X.; Li, F. Analyzing the sustainability of China's industrial sectors: A data-driven approach with total energy consumption constraint. *Ecol. Indic.* **2021**, *122*, 107235. [CrossRef]
2. Brodny, J.; Tutak, M. Analysis of the efficiency and structure of energy consumption in the industrial sector in the European Union countries between 1995 and 2019. *Sci. Total Environ.* **2022**, *808*, 152052. [CrossRef] [PubMed]
3. Liu, H.; Fan, L.; Shao, Z.X. Threshold effects of energy consumption, technological innovation, and supply chain management on enterprise performance in China's manufacturing industry. *J. Environ. Manag.* **2021**, *300*, 113687. [CrossRef] [PubMed]
4. Kahraman, A.; Kantardzic, M.; Kahraman, M.M. A Data-Driven Multi-Regime Approach for Predicting Energy Consumption. *Energies* **2021**, *14*, 6763. [CrossRef]
5. Chen, Y.; Luca, G. Technologies Supporting Artificial Intelligence and Robotics Application Development. *J. Artif. Intell. Technol.* **2021**, *1*, 1–8. [CrossRef]

6. Lin, K.; Zhao, H. The Impact of Green Finance on the Ecologicalization of Urban Industrial Structure-Based on GMM of Dynamic Panel System. *J. Artif. Intell. Technol.* **2022**, *2*, 123–129. [CrossRef]
7. Li, H.; Wang, W.; Fan, L. A novel hybrid MCDM model for machine tool selection using fuzzy DEMATEL, entropy weighting and later defuzzification VIKOR. *Appl. Soft Comput.* **2020**, *91*, 106207. [CrossRef]
8. Liu, S.H.; Du, Y.B.; Yao, K.H.; Tang, D.B. Multi-objective Optimum Seeking Method of Intelligent Manufacturing Oriented CNC Machine Tool. *Trans. Chin. Soc. Agric. Mach.* **2017**, *48*, 396–404.
9. Zhou, L.X.; Yuan, B.; Wang, Y.C. The Optimization Selection of Machine Tool for Green Manufacturing. *Modul. Mach. Tool Autom. Manuf. Tech.* **2018**, *02*, 157–160.
10. Li, L.; Wang, Y.C.; Liu, X.C.; Tang, Y.; Ye, L. Machine Tool Equipment Selection Based on TOPSIS-AHP. *Modul. Mach. Tool Autom. Manuf. Tech.* **2016**, *12*, 129–132.
11. Han, Z.Q.; Shan, W.B.; He, T.F. Decision on green process scheme of mechanical processing based on entropy weight and TOPSIS. *Mod. Manuf. Eng.* **2020**, *08*, 87–91.
12. Zanuto, R.; Hassui, A.; Lima, F. Environmental impacts-based milling process planning using a life cycle assessment tool. *J. Clean. Prod.* **2019**, *206*, 349–355. [CrossRef]
13. Klink, A.; Arntz, K.; Johannsen, L. Technology-based assessment of subtractive machining processes for mold manufacture. *Procedia CIRP* **2018**, *71*, 401–406. [CrossRef]
14. Liu, J.F.; Zhao, P.; Zhou, H.G. Digital twin-driven machining process evaluation method. *Comput. Integr. Manuf. Syst.* **2019**, *25*, 1600–1610.
15. Chen, N.; Barnawal, P.; Frank, M.C. Automated post machining process planning for a new hybrid manufacturing method of additive manufacturing and rapid machining. *Rapid Prototyp. J.* **2018**, *24*, 1077–1090. [CrossRef]
16. Komatsu, W.; Nakamoto, K. Machining process analysis for machine tool selection based on form-shaping motions. *Precis. Eng.* **2021**, *67*, 199–211. [CrossRef]
17. Koremura, K.; Inoue, Y.; Nakamoto, K. Machining Process Evaluation Indices for Developing a Computer Aided Process Planning System. *Int. J. Autom. Technol.* **2017**, *11*, 242–250. [CrossRef]
18. Han, C.; Luo, M.; Zhang, D. Optimization of varying-parameter drilling for multi-hole parts using metaheuristic algorithm coupled with self-adaptive penalty method. *Appl. Soft Comput.* **2020**, *95*, 106489. [CrossRef]
19. He, K.; Hong, H.; Tang, R. Analysis of Multi-Objective Optimization of Machining Allowance Distribution and Parameters for Energy Saving Strategy. *Sustainability* **2020**, *12*, 638. [CrossRef]
20. Wang, Q.L.; Wei, P.; Duan, X.H. Multi-objective Optimization of Computer Numerical Control Turning Process Parameters Based on Response Surface Method and Artificial Bee Colony Algorithm. *Ind. Eng. Manag.* **2022**, *27*, 117–126.
21. Li, Y.F.; Xiong, M.; He, Y.; Xiong, J.J.; Tian, X.C.; Mativenga, P. Multi-objective optimization of laser welding process parameters: The trade-offs between energy consumption and welding quality. *Opt. Laser Technol.* **2022**, *149*, 107861. [CrossRef]
22. Jia, S.; Yuan, H.; Ren, D. Power and Energy Consumption Acquisition and Energy-Saving Control Method of CNC Machine Tool Drilling Process. China Patent 108037734A, 15 May 2018.
23. Xiao, Y.; Jiang, Z.; Gu, Q.; Yan, W.; Wang, R. A novel approach to CNC machining center processing parameters optimization considering energy-saving and low-cost. *J. Manuf. Syst.* **2021**, *59*, 535–548. [CrossRef]
24. Ma, H.; Liu, W.; Zhou, X. An effective and automatic approach for parameters optimization of complex end milling process based on virtual machining. *J. Intell. Manuf.* **2020**, *31*, 967–984. [CrossRef]
25. Zhang, S.B.; Zhang, S. Auxiliary Process Time Modeling and Machining Step Sequencing Optimization of Box Parts. *Modul. Mach. Tool Autom. Manuf. Tech.* **2022**, *7*, 90–94, 98.
26. Wang, R.P.; Yi, J. Characteristics and Mission of Management Thinking with Chinese Characteristics Based on the Business Compass Perspective. In Proceedings of the 8th International Symposium on Project Management (ISPM 2020), Beijing, China, 4–5 July 2020.
27. Chen, X. Introduction to Taoist philosophy. *Chin. Philos.* **2019**, *106*, 14.
28. Sun, X.P. Taoism Naturalistic Technology Views. *Stud. Dialectics Nat.* **2022**, *38*, 42–47.
29. Wang, R.P. *Business Compass*; Science Press China: Beijing, China, 2020.
30. Deng, W.; Luo, Y.; Luo, J. Optimization of milling parameters based on low energy consumption. *Chin. J. Constr. Mach.* **2019**, *17*, 397–400.
31. Xiao, Y.; Zhao, R.; Yan, W.; Zhu, X. Analysis and Evaluation of Energy Consumption and Carbon Emission Levels of Products Produced by Different Kinds of Equipment Based on Green Development Concept. *Sustainability* **2022**, *14*, 7631. [CrossRef]
32. Xie, J.; Ma, J.H.; Luo, X. Study on Energy Consumption Model and Cutting Parameter Decision Method of Machine Tool Oriented to Energy Saving Optimization. *J. Chongqing Univ. Technol. (Nat. Sci.)* **2020**, *34*, 77–86.
33. Xiao, Y.; Wang, R.; Yan, W.; Ma, L. Optimum Design of Blank Dimensions Guided by a Business Compass in the Machining Process. *Processes* **2021**, *9*, 1286. [CrossRef]
34. Jiang, X.; Li, S. BAS: Beetle Antennae Search Algorithm for Optimization Problems. *Int. J. Robot. Control* **2018**, *1*, 1–5. [CrossRef]
35. Hao, J.; Huang, J.; Zhang, A. Optimal coordinated control of hybrid AC/VSC-HVDC system integrated with DFIG via cooperative beetle antennae search algorithm. *PLoS ONE* **2020**, *15*, e0242316. [CrossRef] [PubMed]

36. Jie, Q.; Ping, W.; Cpa, B. Joint application of multi-object beetle antennae search algorithm and BAS-BP fuel cost forecast network on optimal active power dispatch problems. *Knowl.-Based Syst.* **2021**, *226*, 107149. [CrossRef]
37. Zhang, J.; Wang, L. Fault Diagnosis of Hydraulic Pumps Based on Support Vector Machine Optimized by Beetle Antennae Search. *Noise Vib. Control* **2022**, *42*, 5.