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Application of adaptive ant colony algorithm in optimization of machine process manufacturing route

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Abstract. Because there is no a standard design management concept in the mechanical manufacturing industry, the quality of process design results is not high. Therefore, the application of adaptive ant colony algorithm in the optimization of machine process manufacturing route was discussed and analyzed in this paper. The principles of bionics ant colony algorithm, the mechanical process route optimization based on adaptive ant colony algorithm and its scheduling design and route optimization verification algorithm were introduced. Taking the manufacturing process of the gear shaft of Company A as an example, the adaptive ant colony optimization design was carried out, and the manufacturing scheduling problem was verified. The results show that the optimized manufacturing route based on adaptive ant colony algorithm can effectively improve the enterprise's machinery manufacturing efficiency and corporate profits.

Key words. Adaptive ant colony algorithm, mechanical process manufacturing route, optimization.

1. Introduction

With the fierce market competition in recent years, the demand for diversified customers has rapidly developed, but also the speed of the product life cycle has become shorter and shorter. Therefore, the society has also put forward higher requirements for part of the process design [1]. As a bridge connecting product design and manufacture, the design process of parts processing is empirical highly. This process has a high degree of dependence on the environment. At present, most enterprises in the quality of our process design still rely on the quality and

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experience of designers [2]. Although there are a number of mature process examples, its inheritance cannot be used effectively, thus wasting a lot of time and effort in some repetitive design work. At the same time, because there is no standard design and management concept and standard, the quality of process design result is not high, which makes the process design restrict the development of the enterprise. Therefore, it is necessary to optimize the process design process. The quality of process design needs to be improved and the existing mature design examples need to be reused, which can be used as the research focus of process design [3].

In view of the optimization of mechanical manufacturing process, foreign scholars have analyzed the design of CAPP process in the process of product design. Foreign scholars have found that contemporary design cannot take into account the product features while considering the characteristics of complex and diversified manufacturing resources fully. And foreign scholars believe that the integration of product design is to improve product flow route design efficiency. In order to prevent the algorithm from falling into the local optimal solution or the excessive number of components and the complexity of the part structure causing the iterative speed to be too slow, domestic scholars have adaptively treated the evaporation of pheromone in the process of ant transfer on the basis of ant colony algorithm, so as to guarantee the convergence speed of the ant colony algorithm and improve the efficiency of the process route generation [4].

2. State of the art

Attention to bionics from people originated in the middle of 50 s. Artificial immune algorithm, neural network, ant colony algorithm, genetic algorithm and other new algorithms are proposed based on the principle of bionics. Researchers have done a lot of experiments and optimization deficiencies for the shortcomings of ant colony algorithm. The application field of ant colony algorithm is mature, and the application field is expanded gradually [5]. Ant colony algorithm: the ants begin to explore food from the cave without knowing where there is food. Ants will be able to use their own path to make other companions aware of chemicals in this process to exchange information for each other and find the best path finally [6]. A new heuristic optimization algorithm which is called ant colony algorithm is proposed in this way. Ant colony algorithm can be regarded as a mathematical model to solve the spatial parameterized probability distribution model [7]. In fact, according to the pheromone concentration, the algorithm updates the optimal solution of the algorithm by searching in the probability distribution model continuously.

2.1. Methodology

2.2. Principles of ant colony algorithm

When ants are looking for food sources, they can release unique pheromones on their routes. Ants can sense the presence and intensity of matter during movement, and guide the direction of movement so that ants tend to move toward high intensity of matter [8]. When they encounter intersections that have not yet passed, they select a path randomly and release the pheromone associated with the path length. The longer the ant's path, the less information it releases. The more ants on the path, the more likely the latter will choose the path. Thus, the collective behavior of ant colonies represented by a large number of ants shows positive feedback phenomena. The amount of information on the optimal path is more and more, and the amount of information on the other path decreases as time goes on. Finally, the entire ant colony will find the best path [9].

The number of ants is set to m. These ants have the memory function and have the following characteristics:

(1) According to the concentration of network pheromone and heuristic information, ants are moved to the next city that is the next node, they have corresponding transition probability.

(2) The visited nodes are placed in the tabu list, and the ants will no longer access the existing city or node in the tabu table.

(3) The ants will have certain rules at the edge of the pheromone just becoming part of the local update after a step. And the ants will select global updates after they have gone through the entire network [9].

2.3. Optimization of machine manufacturing process based on adaptive ant colony algorithm

The core of the process route optimization design is the design process of all processing methods to optimize the structural features of each component. Process route optimization selects machining methods, processing equipment and mechanical information to achieve design dimensions and accuracy of parts. This process is a multi-objective optimization problem because of the need of considering various machining accuracy, location reference, working time and cost. Routing optimization and constraints include processing order and manufacturing resource constraints [10]. The optimization of routing is to find a sequence of processes that is optimal for multiple objectives (precision, cost, work hour, etc.) under these constraints. There are three hypotheses when we build ant colony algorithm:

(1) Ants communicate with each other by making pheromones as medium. Each ant responds only to a small fraction of its surroundings.

(2) The direction of action of ants is entirely based on the concentration of pheromones, that is to say, the direction of action is the highest concentration of pheromone.

(3) The behavior of a single ant is random. The group behavior is highly ordered because of the internal self-organization process [11].

The choice of each processing element to the next processing element requires consideration of various factors. Therefore, in addition to determining the pheromone concentration, the subordinate group should also consider some constraints when transferring the nodes. The constraints fall into the following two categories in the process of optimizing the design process:

The first is to deal with the order of constraints. The "baseline first" principle determines that the scheduling process requires a fine work base to provide a more accurate benchmark for subsequent processing. The principle of "first thick, later fine" refers to the finishing order of rough processing from one to half. As a result of the above principles, it is necessary to establish a priority processing matrix at initialization

$$p_{ij} = 1 \,. \tag{1}$$

Formula (1) indicates that the machining primitive j is processed prior to the primitive i. If $p_{ij} = 0$ is 0, it means other. The priority processing design route matrix is as follows:

$$P(p_{ij}) = \begin{bmatrix} 0 & 0 & \cdots & 1 & \cdots & 0 \\ 1 & 0 & \cdots & 0 & \cdots & 1 \\ \vdots & \vdots & & \vdots & & \vdots \\ 0 & 1 & \cdots & 1 & \cdots & 0 \\ \vdots & \vdots & & \vdots & & \vdots \\ 1 & 1 & \cdots & 0 & \cdots & 0 \end{bmatrix} . \tag{2}$$

The entire priority processing matrix is updated after each processing element is completed. The corresponding column of the machining primitive is set to 0. One is that the processing element has been processed and will not constrain the processing of other primitives [12].

The other is the restriction of processing equipment. The machining design is often restricted by the existing processing equipment to a great extent. Enterprise or processing unit determines the type of processing equipment on the basis of consideration of cost. The model is certified by experts, and the cost is optimal under the condition of meeting the processing requirements [13]. However, the processing of resources is limited to some extent, and the design process should consider how to ensure the utilization and processing efficiency of manufacturing resources. Frequent replacement of machine tools, tools, fixtures will increase the processing auxiliary time greatly and reduce processing efficiency. Therefore, in order to ensure the efficiency of mechanical manufacturing process, the best machining accuracy and cost, it is necessary to try to adjust the order of processing in the design process. Number of machines replaced times replaces tools to replace minimum quantities. At the same time, the utilization rate of various processing resources is ensured [14]. In addition to considering the characteristics of the parts, it is necessary to integrate geometric constraints, feature accuracy, manufacturing resource selection, process personnel experience and other factors. Mechanical process manufacturing site is shown in Fig. 1.

2.4. Optimization of mechanical manufacturing scheduling design and verification

The effects of manufacturing results on the interests of enterprises are manifold. The merits of manufacturing results should be a comprehensive evaluation of a series of issues such as order time, production cost, inventory cost and so on. However, the evaluation of manufacturing solutions is usually performed on a small number

Fig. 1. Mechanical process manufacturing site

of questions or on the relative validity of each indicator in previous manufacturing studies. Business managers considering all aspects of corporate interests cannot be reflected adequately without flexibility. This scheme can only be extensible to describe the way in which business interests are presented. Therefore, in order to make that the optimization results of mechanical manufacturing process are in line with the interests of enterprises, the enterprise benefit evaluation system was established in this paper, and the default cost or profit, direct production costs, inventory costs were considered as a measure of the composite index.

The solution of manufacturing scheduling is defined as x, and each factor that affects the interests of an enterprise has an evaluation function f_i. Each factor that affects the interests of an enterprise has an evaluation value $y_i = f_i(x)$. The evaluation of enterprise benefits can be expressed as

$$y = f(y_1, y_2, \cdots, y_n) . \tag{3}$$

Function f in the above formula must not be a simple function.

However, several manufacturing modes commonly used in enterprises include Make To Stock (MTS), Make To Order (MTO), Assembly To Order (ATO) and Engineering To Order (ETO). In addition to the inventory model oriented manufacturing, the order determines the revenue of the enterprise in other manufacturing models. Therefore, enterprises can increase their interests only by reducing their costs. For the inventory model oriented manufacturing, the income of the enterprise is also predictable after the master manufacturing plan is determined at the market level. Therefore, the way to increase business interests is often to cut costs rather than expand revenues at the manufacturing scheduling level.

In consideration of that part of the impact of corporate interest is the loss of intangible costs or the benefits of monetary measurement, the impact of other units of measurement will be assessed as a monetary measurement company according to the specific values and cultural circumstances. Finally, the evaluation of various costs in monetary terms is an assessment of the interests of the enterprise. Depending on the importance of the customer to the business, the same order is the invisible loss caused by the delayed delivery of the enterprise. The customer should handle the relationship with the customer and avoid important customer orders as late as possible. The second point is that the size of the product value will also affect the default loss. The greater the volume is, the greater the default loss is. Finally, the longer the order delivery delay, the greater the adverse impact on the enterprise, and the higher the default loss. The main verification and parameter analysis theory should be considered in the design of the system architecture. Therefore, the results that are convenient for case studies and analyses should be given priority. As a result, data storage uses text file format modified easily, and the output of the algorithm uses a machine friendly form. When it is required, the machine friendly output of the algorithm is transformed into a user friendly form by using separate modules. The snapshot of the production resource stored at the lower level is the BOM, the list of devices, and the scheduling target [15]. In general, there are user friendly data structure forms and machine friendly data structure forms mainly. User friendly data forms are stored in text files for ease of generation and modification. The system architecture is shown in Fig. 2.

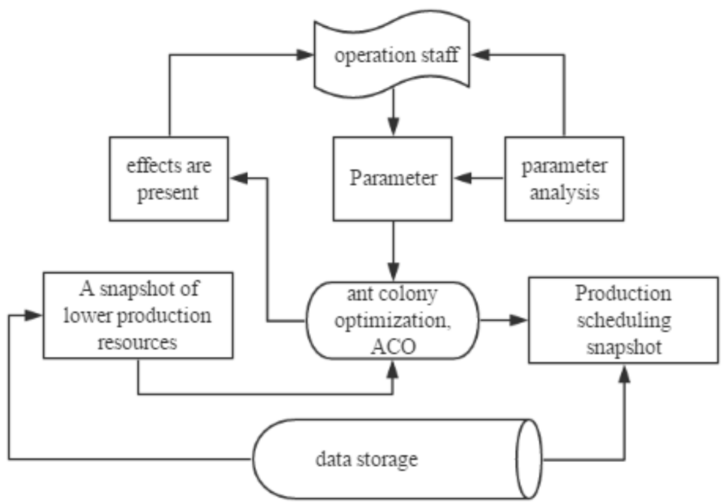

Fig. 2. Ant colony algorithm validation architecture design

3. Result analysis and discussion

The mechanical manufacturing process of the gear shaft of the company A was taken as an example. Pheromone is the most important parameter factor in ant colony algorithm. The snail ants give birth to inherent information that is used to communicate with each other in search of the shortest path during the cruise. According to the relationship between the pheromone and the processing primitives, the route matrix is shown in Table 1.

Then, adaptive route length, iteration number and the evaluation of enterprise's benefit were obtained by simulation of company A' gear shaft mechanical process manufacturing route. The number of ants was set to 50. The data is shown in Table

2.

Table 1. Part of the route matrix

Processing primitives	1	2	3	4	5
1	0	1	1	0	0
2	1	1	0	1	1
3	1	0	0	1	1
4	1	1	0	0	1
5	0	1	0	1	1

Table 2. Variable value of mechanical process route

Serial number	Adaptive route length	Iteration number	Benefit evaluation (y)
1	26.9	76	88.57
2	28.6	22	84.21
3	30.5	15	79.22
4	32.6	8	73.45
5	35.1	5	70.78

It can be seen from Table 2 that the global search capability was related to the number of mother ants directly. The larger mother ant number was a good thing to improve the global search ability, but it would reduce the convergence speed of the algorithm. If the complexity of the problem was high, the number of mother ants was relatively small. The path length of mechanical process was related to the number of iterations based on adaptive ant colony. The more of the number of iterations, the higher the degree of optimization of the manufacturing route was. Moreover, as far as the evaluation of enterprise interests, the shorter of the manufacturing process, the more effective the production efficiency would be, and the benefit of the enterprise would increase. When the number of iterations was as high as 76, the adaptive mechanical manufacturing route was 26.9, and the benefit evaluation was 88.57.

The results of the optimization of the mechanical manufacturing process must be validated to avoid the effects of non-quantifiable factors in the manufacturing process. Adaptive ant colony algorithm and the correctness of production scheduling problem in solving manufacturing environment with complicated process route were verified. Firstly, the same parameter runs, including random number seeds, were used to validate the system. The correctness of the algorithm was verified by two scheduling objectives, namely, the shortest processing time and the maximization of enterprise benefits. And the correctness of the algorithm was verified when the work center had an expected downtime. Supposing that the design process manufacturing route of company A is shown in Fig. 3: (letters represent the chain of operations needed for this process, and data after letters represent assembly quantities).

The enterprise manufacturing work center table is set out as follows, and this table applies to the production flow of such process products:

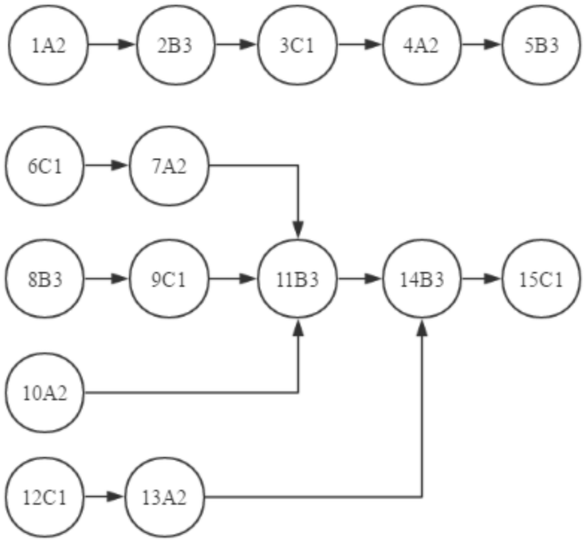

Fig. 3. Process route

Table 3. Work center table

Work center number	Process chain	Processing rate	Unit cost	Predictable downtime
1	A	800	400	NULL
2	B	200	300	NULL
3	B	300	300	NULL
4	C	400	200	NULL
5	C	500	300	NULL
6	C	600	400	NULL

The order form is shown in Table 4.

Table 3. Work center table

Order number	Final process	Batch	Delivery time	Liquidated damages
1	5	600	100	200
2	15	400	100	300

The production cost and the default cost were used as the basis of the enterprise benefit evaluation, and the calculation of the default cost was simplified as the tardiness time multiplied by the liquidated damages rate. The optimization results are shown in Fig. 4.

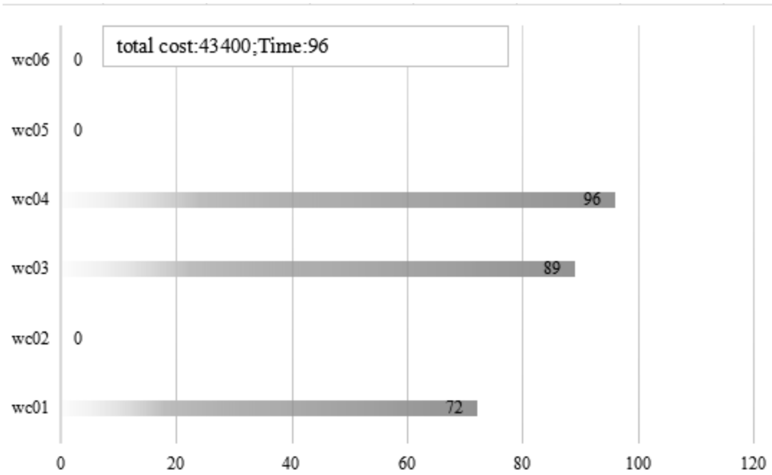

Fig. 4. Optimization results

The scheduling results show that the completion time of the last process was 96. No breach occurred at this time, and the total cost 43400 was the direct production cost. The order delivery time was revised to 70. The optimization results are shown in Fig. 5.

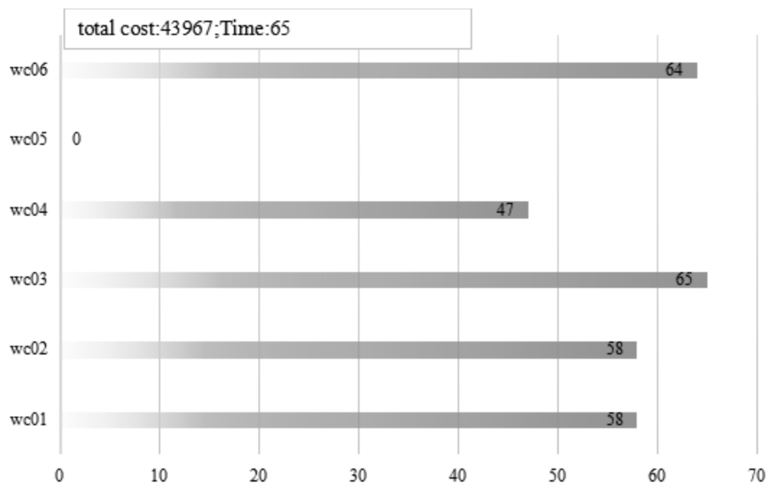

Fig. 5. Optimization results that can be met by order times

When the delivery time was 70, the total cost was 43967, which was greater than the previous scheduling result of 43400. This is because the time will cause the cost of default, and the algorithm arranges a part of the process to the work center with higher production cost. Although this will increase the cost of direct production, it also avoids the occurrence of breach of contract so that the total cost is lowest. That is to say, the interests of enterprises are maximized. Therefore, the ant colony algorithm can solve the production scheduling problem with multiple optimization objectives, complex process routes and environments defined by this example effectively. Ant colony algorithm is better for the optimization of mechanical process route.

4. Conclusion

As the link of product design and manufacture, process design affects the machining efficiency and quality of products to a great extent. However, there is diversity in process design due to the characteristics of parts structure, manufacturing accuracy, processing methods and manufacturing resource selection. Therefore, how to choose the best manufacturing route for the various processing routes for product manufacturing to save costs and improve manufacturing quality is particularly important. The decision making problem of mechanical process manufacturing is transformed into the optimal ordering problem of manufacturing resource substitution rate under the constraints of processing sequence and manufacturing resource. The application of adaptive ant colony algorithm in the optimization of machine process manufacturing route was analyzed in this paper. Firstly, the background and the present situation of the optimization of the mechanical manufacturing route were introduced, and the bionic ant colony algorithm was analyzed. Secondly, the principles of ant colony algorithm, the optimization of mechanical process route based on adaptive ant colony algorithm, the optimization of mechanical manufacturing scheduling design and verification method were analyzed. Finally, the optimized design was carried on by taking the gear shaft mechanical processing route of Company A as the example. And the route verification analysis was carried out based on its manufacturing scheduling factors. Experiments show that ant colony algorithm can optimize the design of mechanical manufacturing process according to the manufacturing process factors, and improve the operation and production efficiency of enterprises.

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