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Research on Flexible workshop Scheduling Based on harmony search Algorithm

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Abstract

The purpose of this paper is to use the harmony search algorithm to solve the scheduling problem of flexible job shop, with the goal of minimizing the maximum completion time. The issue of flexible workshop scheduling is an important research content in the field of production operation management. It involves how to rationally arrange the processing sequence of different jobs on different machines to optimize production efficiency. As a heuristic optimization algorithm, the harmony search algorithm performs well in solving complex optimization problems with its good global search ability and robustness. This paper first establishes a mathematical model of the scheduling problem of flexible job shop, and expounds in detail the basic principle and process of the harmonic search algorithm. Subsequently, we designed a scheduling strategy based on the harmony search algorithm, and by adjusting the algorithm parameters and strategies, we realized the effective optimization of the maximum completion time. The experimental results show that the algorithm can significantly reduce the maximum completion time and improve production efficiency when solving the scheduling problem of flexible work workshops. The research in this paper not only provides a new solution method for the scheduling problem of flexible job shop, but also provides a useful reference for the application of harmonic search algorithm in similar problems.

Keywords

Workshop scheduling problem; Harmony search algorithm; Flexible job shop scheduling; Minimize maximum completion time.

1. Introduction

1.1. Research background

As we all know, manufacturing is an important pillar of the national economy and is of great significance for achieving sustainable development and improving people's living standards. As a large manufacturing country, how to accelerate the transformation and upgrading of the manufacturing industry and improve its innovation capabilities and core competitiveness is a very urgent issue at present. With the rapid progress of information technology, the traditional manufacturing industry has been unable to adapt to the development needs of the new era due to the lag in production efficiency and unreasonable resource allocation [1].As the most widely used technology in the 21st century, artificial intelligence has shown great value in many fields such as medicine, education, industry, and finance. The rise of artificial intelligence has led countries around the world to once again focus their national strategies on the manufacturing industry, with a view to using its power to promote the transformation and upgrading of the manufacturing industry and meet the development requirements of the new era. Germany proposed the “Industry 4.0” strategy in 2013, the United States proposed the industrial Internet strategy, and Japan proposed the industrial revival plan. General Secretary Xi Jinping has also

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pointed out at the conference many times that “manufacturing is the lifeblood of the national economy.” In 2020, China mentioned at the International Trade in Services Conference that it should promote the development of manufacturing in the direction of flexibility, informational, and intelligence through intelligent and green means, and improve the current production model through modern intelligent technology [2].

The production process of an enterprise involves many links, and production scheduling is a vital part of it. It is not only the foundation of the manufacturing system, but also the center of enterprise production organization and management. Production scheduling is directly related to the time planning and resource allocation of the production process. It is a key factor in determining production efficiency and resource utilization efficiency, and it plays a decisive role in improving the competitiveness of enterprises. With the deepening of more and more academic research, effective workshop production scheduling optimization has been proven to significantly improve the rationality of production time, shorten production cycles, reduce production costs and improve production efficiency, thereby bringing higher production capacity and profits to enterprises. Therefore, the research on the optimization of workshop production scheduling has become an important topic to promote the development of manufacturing industry [3].

1.2. Research significance

Intelligent workshop scheduling is the core step in realizing an intelligent production system, and it is a key problem that needs to be solved urgently in the development of advanced manufacturing. Intelligent production scheduling can appropriately allocate available production resources to production tasks over time, which has a direct and critical impact on product delivery and resource cost control[4]. The research object of this topic is to construct a production scheduling model of a flexible workshop based on the harmony search algorithm. Its theoretical significance can be summarized as enriching the application of the harmony search algorithm and providing new ideas to solve the scheduling problem of the flexible workshop in two parts.

Although the Harmony Search Algorithm (HS) has shown its wide application potential in many fields, it is still lacking in the research of the Flexible Job Shop Scheduling Problem (FJSP). In view of this, the purpose of this research is to apply the harmony search algorithm to the solution of flexible workshop scheduling problems, which can not only expand the scope of application of the algorithm, but also help to further verify and demonstrate its excellent performance. In addition, this topic adopts the harmony search algorithm as the core tool for constructing the workshop scheduling model, making full use of its simplicity of operation and excellent search capabilities, so as to provide a more efficient solution for the scheduling of production resources in the manufacturing industry. The algorithm model can not only improve production efficiency, but also reduce energy consumption, reflecting the concept of green manufacturing. Through the research on this topic, we have further expanded the research field of workshop scheduling model construction, and the integrated model developed has cross-disciplinary applicability, which is expected to promote the deep integration of interdisciplinary theoretical innovation and practical application.

Due to the diversification of equipment, the wide variety of products, and the high complexity of production tasks in the flexible workshop, its scheduling problems are very challenging [5]. With its excellent search capabilities, the harmony search algorithm can efficiently provide optimized production scheduling solutions, thereby improving production efficiency. This is of great practical significance to manufacturing enterprises in the current context of globalization and fierce market competition. In addition, an efficient production scheduling scheme can also reduce the overuse of equipment and the overwork of workers, and further reduce equipment maintenance costs and labor costs. At the same time, this topic also helps to improve the punctuality of delivery. Through effective scheduling, production tasks can be ensured to be completed on time to meet customer delivery needs [6].

1.3. Research status at home and abroad

1.3.1. Research status of Harmony search Algorithm

Harmony search algorithm, this heuristic algorithm was innovatively proposed by Korean scholar Geem. It simulates the improvisation process of musicians and shows unique advantages. The algorithm is not only simple to understand and easy to implement, but also has strong search capabilities and excellent global convergence [7].Since its birth, the harmony search algorithm has been widely used in many fields, such as the problem of multi-target workshop scheduling, the problem of optimal allocation of water resources, the 0-1 backpack problem, the shortest path problem, and the attribute selection problem, etc., showing its wide applicability and practicality.

Yang Jia [8] et al. proposed a wireless sensor network multipath algorithm based on the harmony search algorithm, which effectively reduces the delay of data transmission, improves the reliability of data and extends the service life of the network; Liu Guanquan [9] et al. Used the harmony search algorithm to optimize the layout of the workshop, and verified that the use of the algorithm can effectively reduce the handling cost of workshop materials and increase the closeness of non-logistics relationships in the workshop; Li Hexiang [10] et al. Applied the harmony search algorithm to automatic target tracking and realization, and found that the harmony search algorithm has better robustness than other algorithms and can accurately track targets; Yang Hua [11] et al. proposed a population search algorithm based on the cell-type membrane calculation framework to enrich population diversity and improve the search ability of the algorithm. The results show that the algorithm has better optimization ability and practicality.

1.3.2. Research status of scheduling issues in flexible workplaces

As an important extension of the Job shop Problem (JSP), FJSP breaks the restriction of the singularity of process processing resources, thus greatly enriching the solution space of the problem. Compared with traditional JSP, FJSP is closer to the actual operation of modern workshops, so it is regarded as one of the core issues in modern manufacturing and has become a hot topic in current research.

Karthikeya[12] et al. proposed a hybrid discrete bee colony algorithm to solve the scheduling problem of multi-objective assembly workshop under resource constraints, in which the optimization goals include completion time, total machine load and critical machine load, but this method requires decision makers to determine the weight of the target value according to the actual situation; Long[13] et al. Artificially solve the dynamic FJSP with inserted workpieces, combine reinforcement learning and ABC, and design a dynamic adaptive learning artificial bee colony optimization algorithm, which can determine the update dimension based on the convergence accuracy during each iteration, dynamically process workpieces that have not started processing, and update the current scheduling scheme; Chen [14] Et al. proposed a new genetic algorithm for the objective function of the maximum completion time of FJSP. According to the characteristics of FJSP, the coding part is divided into two parts: machine selection and process sorting. A high-quality scheduling scheme has been obtained, which provides a good idea for subsequent genetic algorithms to solve FJSP; Luo[15] et al. Used the deep reinforcement learning network algorithm to solve the dynamic FJSP with random task insertion; Zhang Guohui[16] et al. Further combined with the characteristics of FJSP, proposed an initialization method that considers the machine load, improves the quality of the initial solution, and Reasonable coding methods, crossover operators and variation operators are designed to improve the solving efficiency; Meng Leilei [17] et al. proposed a hybrid frog jump algorithm and introduced variable neighborhood search into the algorithm to reduce the

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maximum processing time of workshop scheduling problems. Li Tieke[18] et al. used cultural algorithms to extract the knowledge characteristics of the solution, improved the random operation of the selection operator, guided the genetic algorithm to perform the selection operation, and improved the solution quality of FJSP; Shi[19] et al. Proposed an intelligent scheduling algorithm based on reinforcement learning for the scheduling problem of automated production lines. At present, the application of harmony search algorithm in FJSP is relatively rare, but the structural characteristics and strong search capabilities of harmony search algorithm still have great potential for solving FJSP problems.

2. Basic theoretical analysis

2.1. Swarm Intelligence

Swarm Intelligence (SI) is a class of optimization algorithms inspired by the evolution and intelligence phenomena of nature. By simulating biological evolution, group behavior, or physical phenomena, they provide a new perspective and efficient means for solving complex optimization problems. Although its mechanism is similar to physics-based algorithms to some extent, the group intelligence algorithm uniquely uses simulated biological collective and social intelligence for navigation in the search process [20]. As an important branch of meta-heuristic algorithms, group intelligence algorithms occupy an important position in the field of optimization because of their distinctive characteristics such as simple operation and easy implementation, and few adjustment parameters. At present, particle swarm optimization and artificial bee colony algorithms are the most concerned and popular representatives of swarm intelligence algorithms. The particle swarm optimization algorithm draws on the wisdom of the social behavior of bird groups. Through the collaboration of multiple particles, it chases the best particles and their positions together, and gradually approaches the optimal solution of the problem [21]. The artificial bee colony algorithm is inspired by the social behavior of bees looking for the shortest path between nests and food. By simulating the foraging behavior of bees, it realizes an effective solution to the optimization problem [22].

2.2. Harmony search algorithm

The harmony search algorithm was proposed by the Korean scholar Geem in 2001. It is an enlightening algorithm designed to simulate the improvisation process of musicians. In music creation, musicians carefully select and constantly adjust the tones of various musical instruments to finally achieve a harmonious and pleasant state of harmony. Therefore, the HS algorithm can be regarded as a means to solve the global optimization problem.

The harmony search algorithm first constructs a structure called Harmony Memory (HM) to store candidate solutions in the search process. In the initial stage, the size of the harmony Memory (HMS) needs to be set. The size of the harmony memory determines the number of solutions that the algorithm can refer to in each iteration. Subsequently, the algorithm selects a new solution from the harmony memory library based on the Harmony Memory Considering Rate (HMCR). The harmony memory considering probability determines the extent to which the harmony search algorithm relies on historical information to generate new candidate solutions. At the same time, new solutions are randomly generated in the feasible domain of variables with probability 1-HMCR, thereby increasing the diversity of harmonic search algorithms and the ability to explore unknown spaces. After generating a new solution, the harmony search algorithm will decide whether the new solution needs to be locally disturbed based on the Pitch Adjusting Rate (PAR) [23]. This step is similar to fine-tuning in music creation, aiming to improve the quality of music through subtle adjustments. In the end, the algorithm will determine whether the new solution is better than the worst solution in the harmony memory based on the value of the fitness function. If the new solution is better, replace it with the worst solution, thereby gradually optimizing the quality of the solution in the sound memory. If the new solution does not meet the replacement conditions, the algorithm will repeat the above steps until the preset termination conditions are reached, such as reaching the maximum number of iterations or the quality of the solution meets the preset requirements.

With its simple structure, less parameter adjustment, strong versatility, strong search ability and fast convergence speed, the HS algorithm has shown great potential in optimization problem solving. This algorithm not only brings new perspectives and tools to the field of optimization, but also provides us with new ideas for understanding and simulating complex phenomena in nature.

3. Improved harmony search algorithm to solve the scheduling problem of single-target flexible workshop

3.1. Overview of single-target flexible workshop problems

3.1.1. SOFJSP problem description

Flexible workshop scheduling is an expansion of traditional workshop problems, which is more flexible, closer to life, and more practical. FJSP refers to the production model where n workpieces are processed on m machines. Each workpiece has multiple processing processes, and each process can choose any machine in the machine set for processing. The solution of FJSP mainly focuses on two core sub-problems: one is to choose the most suitable processing machine for each process; the other is to reasonably arrange the processing sequence of the process, that is, to determine the starting processing time of each process on the machine [24].By solving these two sub-problems, the production process can be effectively optimized and manufacturing efficiency can be improved. Common performance indicators in FJSP include minimizing the maximum completion time, minimizing machine load, and minimizing processing costs.

Table 1 shows an example of an FJSP workshop. The workshop consists of five processing machines and three workpieces. Each workpiece has three processes. Each process can be processed on any machine. The specific processing time is shown in the table 1.

Table 1:an example of an FJSP workshop

workpiece	Process	Machine set				
		M_1	M_2	M_3	M_4	M_5
J1	O_{11}	2	3	3	4	7
	O_{12}	3	4	6	5	4
	O_{13}	5	5	4	3	5
J2	O_{21}	5	4	3	7	4
	O_{22}	4	3	5	6	8
	O_{23}	3	7	6	4	5
J3	O_{31}	4	5	7	6	3
	O_{32}	5	6	4	3	6
	O_{33}	4	3	6	7	4

In the process of solving FJSP, the actual constraints will be abstract into a mathematical model. The specific constraints are as follows:

ISSN: 2710-0170

(1) In the same workpiece, the process has a priority, and the next process can only be processed after the previous process is processed. The processing priority of different workpieces is the same, and the process processing priority of different workpieces is also the same.

(2) Once any process starts, it cannot be interrupted, and the preparation time and transfer time of the workpiece are counted within the processing time.

(3) The same process on the same workpiece can only be processed on one machine, and each machine at the same time can only process one process.

(4) At time 0, it is assumed that all machines are idle, and no-load operation is performed from the completion of the machining to the beginning of the next process [25].

SOFJSP is the scheduling problem of single-target flexible job shop and is an important branch of FJSP. Similar to FJSP, SOFJSP faces the same constraints. However, unlike FJSP, the main performance indicator of SOFJSP is to minimize the maximum completion time. This means that when solving SOFJSP, our goal is to find a scheduling solution that makes the latest completion time of all jobs as short as possible. In order to achieve this goal, we need to comprehensively consider various constraints, as well as the dependencies and priorities between different jobs, so as to find the optimal scheduling scheme. This not only helps to improve the production efficiency of the workshop, but also reduces the waste of resources and waiting time. In summary, SOFJSP is a challenging problem, and its solution is of great significance for improving the production efficiency of the workshop and reducing manufacturing costs. Through in-depth research on the characteristics and algorithm design of SOFJSP, we can provide strong support for enterprises to achieve green and efficient sustainable development.

3.2. Single-target flexible workshop problem solving

3.2.1. Encoding and decoding

In practical applications, any optimization algorithm needs to encode the problem, transform the solution of the problem into a coded form that the algorithm can handle, and then carry out a series of operations and operations of the algorithm. FJSP's encoding and decoding strategies are rich and diverse. Common encoding methods include encoding based on machine information, encoding based on process information, and encoding based on disjunctive diagrams. In order to fully express the information of the individual population, we usually choose one or a combination of multiple coding forms to characterize the individual [26].Therefore, choosing the appropriate coding method is one of the key steps to solve the FJSP problem, which directly affects the performance and solving efficiency of the algorithm. In view of the objective function of minimizing the maximum completion time, this paper adopts a process-based coding method and divides the coding into two parts: processing sequence coding and machine selection coding. The length of the sequence of process coding is equal to the sum of all the processes used. The processes of the same workpiece use the same symbol. The number of occurrences of the workpiece symbol J represents the jth process of the workpiece. The sequence length of the machine selection code is the same as the process sequence, and each element represents the processing machine selected by the corresponding process [27].

Decoding corresponds to encoding, and an appropriate and efficient decoding algorithm can better transform encoding into a scheduling scheme. The decoding algorithm is carried out in two parts: the machine selection part and the process sorting part. First, the machine selection part is decoding, and then the process sorting part is decoding according to the results selected by the machine. The main process of decoding the machine selection part of the process is to store the machine selection result and the processing time of the corresponding machine in the machine matrix and time matrix for the decoding of the sorting part of the process.

ISSN: 2710-0170

In the machine selection process, the tones corresponding to the vector serial number are read in the order from left to right, and the vector serial number is converted into the corresponding process. Then, the machine value is selected from the set of optional machines of the corresponding process, and the machine value is stored in the corresponding position of the machine matrix. Then select the time value in the optional machining time set of the corresponding process, and store the time value in the corresponding position of the time matrix. Cycle through the above steps to the end of all processes. The process decoding mainly uses active decoding to obtain the maximum completion time of the scheduling scheme. In the process sorting and harmony, each tone is read in turn, and converted into the corresponding process according to the reverse thinking of the coding rules.; Then obtain the processing machine and machine processing time selected for the process in the machine matrix and time matrix [28]. Then determine whether the process is the first process on the selected machine. If it is the first process, perform the following (a) and (b) operations; if not, then continue to Step Two.(a) If the process is the first process of the workpiece to be processed, the processing time will be timed from zero.(b) If the process is not the first process of the workpiece being processed, the processing time will be accumulated and timed from the time after the end of the previous process of the workpiece. Step 2: Find all the idle periods on the selected machine that are greater than the processing time. If so, perform the following (c) and (d) operations. If not, then start processing the current process at the end of the processing on the selected machine.(c) If the process is the first process of the processed workpiece, the processing time of the process is inserted into the first idle period, and then the cycle is jumped out.(d) If the process is not the first process of the workpiece being processed, you need to consider that the idle time is behind the processing time of the previous process of the workpiece. If satisfied, insert out of the cycle, if not satisfied, start processing the current process at the end of the processing on the machine M. Step 3: Update the accumulated processing time on the machine. Step 4: Cycle through the above steps to the end of all processes.

3.2.2. Initialize the harmony memory

Similar to other intelligent algorithms, the initialization of the harmony memory of the harmony search algorithm also directly affects the final solution of the harmony search. There are two requirements for the initialization of the harmony memory bank: one is to maintain the diversity of the harmony memory bank, expand the search scope, and increase the probability of searching for the global optimal solution; the second is to ensure the quality of the solution initialized by the harmony memory bank, the quality of the solution affects the convergence rate.

3.2.3. Improvise new harmony

Step 1: The harmony algorithm generates a random number r1 at [0,1] during each iteration, and compares r1 with HMCR. If r1 <HMCR, a harmony variable is randomly selected from the harmony memory, otherwise a harmony variable is randomly generated from the solution space. Step 2: Adjust the harmony obtained in STEP 1. If the harmony is obtained from the MEMORY BANK, you may need to fine-tune the harmony. A random number r2 is generated at [0,1]. If r2 <PAR, the resulting harmony is fine-tuned according to the fine-tuning method BW, otherwise no adjustments WILL be made [29].

HMCR is a more important parameter in HS. The generation of each new solution will depend on HMCR. Therefore, HMCR takes a larger value, usually HMCR∈(0.9,1), PAR plays a role in controlling local search in harmonic search. It can make the search result locally optimal, and its value is generally 0.1~0.5.

3.2.4. Update the harmony search library

The objective function evaluation of multiple new harmonies generated by each iteration is carried out, and the new harmonies created are compared with the harmonies preserved in the

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harmony memory. If it is better than the worst harmony in the memory bank, the harmony is retained; otherwise, the harmony is discarded until the optimal solution is obtained or the constraints are reached.

3.2.5. Algorithm flow

The specific process of HS solving SOFJSP is as follows：

Step 1: Initialize the algorithm parameters. Initialize the experimental case data, the size of the harmony memory HMS, consider the probability of taking the value in the harmony memory HMCR, consider whether to adjust the harmony tone PAR, fine-tune the broadband BW and the number of iterations.

Step 2: Initialize the harmony memory bank. The HM is initialized by a combination of two coding methods, each harmony in the harmony memory is evaluated, and the optimal harmony and the worst harmony are found.

Step 3: Create a new harmony. Two random numbers r1 and r2 are randomly generated, r1 and r2 are compared with HMCR and PAR, and the selected harmony is fine-tuned according to the comparison results.

Step 4: Update the harmony memory. Evaluate the new harmony created, replace the harmony in the harmony memory with a new harmony that is better than the harmony in the harmony memory, and update the optimal harmony and the worst harmony of the harmony library.

Step 5: Repeat Step 3 and Step 4 until the number of iterations is equal to Iter, and stop authoring and updating.

Step 6: Output the optimal harmony and optimal harmony, that is, the operation of the optimal machine selection and process sorting and the minimum and maximum completion time.

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Iteration: 87, Makespan: 38
Iteration: 88, Makespan: 38
Iteration: 89, Makespan: 38
Iteration: 90, Makespan: 38
Iteration: 91, Makespan: 38
Iteration: 92, Makespan: 38
Iteration: 93, Makespan: 37
Iteration: 94, Makespan: 38
Iteration: 95, Makespan: 38
Iteration: 96, Makespan: 38
Iteration: 97, Makespan: 38
Iteration: 98, Makespan: 38
Iteration: 99, Makespan: 38
Iteration: 100, Makespan: 40
Best Makespan: 1  1  1  1  2  2  1  1  1  1  1  3  3  2  1
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Figure 1:The result

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4. Simulation experiment and analysis

4.1. Simulation example experiment

Based on the above discussion, a flexible work workshop scheduling is carried out virtually. Among them, the number of workpieces n=5 and the number of machines m=3. Each workpiece has 3 processing processes. The operation time of the process is randomly generated. The maximum number of iterations is 100, PAR is 0.3, HMCR is 0.7, and BW is 0.1.The operation result is shown in Figure 1：

5. Summary and outlook

The harmony search algorithm has shown significant optimization ability in solving the scheduling problem of single-target flexible job shop. By simulating the harmony process in music creation, the algorithm can effectively explore the solution space and find a high-quality scheduling scheme. However, in the face of complex production environments and changeable job requirements, the harmony search algorithm still needs to be further improved. Future research can focus on the adaptive adjustment of algorithm parameters, the combination with other optimization algorithms, and the expansion of multi-objective flexible workshop scheduling problems. Through these efforts, it is expected to further improve the performance and practicality of the harmony search algorithm, and provide a better solution to the workshop scheduling problem in actual production.

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