ISSN: 2664-9640

Multi-Objective Scheduling Optimization of Flexible Job Shop Considering the Adaptive Weight Adjustment Strategy

Guangyao Bao[1, a]

[1]Sinopec Qingdao Refining & Chemical CO.LTD, Qingdao 266500, China.

[a]bgy.qdlh@sinopec.com

Abstract

The real-time performance of dynamic scheduling of manufacturing resources in workshop requires rapid response capability of scheduling optimization algorithm. Heuristic algorithms with priority rules can quickly respond to production and find better solutions in limited time. The sustainable manufacturing of workshop is related to the sustainable development of enterprises. In order to realize the sustainable production of workshop timely, a heuristic algorithm of integrated rule based on adaptive weight adjustment strategy is proposed. A makespan and energy consumption model of flexible work shop was constructed with the goal of minimizing the completion time and energy consumption based on the characteristics of flexible flow-shop. Integrated rule was designed to intervene scheduling priority, which can achieve hierarchical optimization of workshop machine tools and processes. Adaptive adjusting the index weight by calculating the deviation rate between the index and the average aggregation distance, which can also guide the selection of machine tools and processes in the next stage and obtain a reasonable solution. Finally, the effectiveness of the algorithm and the model is well illustrated through several numerical cases and comparisons.

Keywords

Sustainable manufacturing; flexible flow-shop; integrated rule; adaptive weigh adjustment.

1. Introduction

Currently, with the increasingly serious global climate change and energy crisis, environmental issues have become the focus of global attention. As a high energy consuming industry, manufacturing workshop achieves the effect of energy saving and emission reduction through the procedure sequence and machine tools assignment. The research of energy consumption in flexible flow-shop production is highly valued by domestic and foreign scholars, the corresponding theoretical research results have been obtained. Zhang R[1] verified the key role of production scheduling in reducing energy consumption in factories. In the multi-objective scheduling of time and energy consumption, Taisch M[2]discussed the influence of production scheduling on improving work efficiency and environment. Li[3] conducted scheduling on the multi-objective optimization model of machining process route with the goal of shortest time and lowest carbon emission. In addition, as the basic indicator of workshop scheduling, time is an important part of workshop scheduling, which have an important impact on workshop scheduling ChirkinA M,Bao B[4][5]. Singh M [6] pointed out that shorten the production cycle can make the company respond quickly to the market. In order to be competitive in current production environment, optimizing the time is necessary. Liou[7] et al. studied the job-shop scheduling problem considering the work-piece transportation time, the optimization algorithm combined with particle swarm optimization and genetic algorithm are developed.

Jiang proposed that in order to strengthen the competitiveness of enterprises, under the premise of time, how to more effectively integrate the indicators to achieve multi-objective production has become a key factor. Liu[10] and zhang[8] obtained the best solution through solving the mathematical model of the time and cost simultaneously. SalidoM[9] solved many practical scheduling problems in the process of processing time and cost as optimization objectives.

In summary, scholars have established multi-objective models to solve the problem of flexible flow-shop scheduling optimization from different production perspectives. With the development of multi-objective scheduling research, it has become an important research trend to balance various indexes for production. Min[11]et al. proposed an energy saving model, an improved genetic simulated annealing algorithm was developed to effectively balance the manufacturing process and total energy consumption. HE[12]et al. established energy consumption and time mathematical models by using mixed integer programming, the implemented nested segmentation algorithm was used to achieve energy-saving production in workshops. TANG[13]et al proposed an heuristic algorithm, energy consumption optimization algorithm and heuristic rule combination algorithm based on priority rules for scheduling optimization of flexible workshops. The weights in the above studies are mostly adjusted by fixed weights and random methods, resulting in low accuracy and easy to fall into local optimization.

Based on this, in this paper, the mathematical model of makespan and energy consumption was constructed through the analysis of the correlation between the indicators. An integrated rule was developed based on the model. Machine tools and processes are selected by the rule. In order to realize the balance between energy consumption and makespan, the weight coefficient is adaptively adjusted through the change rate of each index and the average aggregation distance, which can avoid falling into the local optimal solution and obtain the scheme reasonably.

2. Problem Formulation

The flexible job-shop scheduling problem(FJSP) is described as follows: n(i={1,2,..,n})work-pieces are processed on m(k={1,2,…,m})machine tools, each work-piece contains j(j={1,2,…,l})operations, the sequence of the procedure are predetermined. More than one parallel machine tools can be selected for each operation. Different operation leads to the dynamic and variable of production. How to reasonably schedule the procedure sequence and select the machine tool for each operation is the key problem for FJSP sustainable scheduling.

In addition, we supposed that (1) Jobs are independent, and have equal priority. (2) After a job is processed on a machine, it is transported to the next machine immediately, and the transportation time is negligible. (3) All jobs and machines are available at time zero, turning off the idle machines is not allowed and machine failure is not considered. (4) The machine cannot be turned off completely until it has finished all operations assigned to it.

makespan model

The makespan of the workshop means the maximum completion time of all the work-pieces, which can be formulated as bellow.

$$t^{total} = \max F_{ijk} \tag{1}$$

Energy consumption model

The energy consumption of workshop production can be divided into two stages: (1) processing stage; (2) waiting stage. The processing time tijk, processing energy consumption

ISSN: 2664-9640

per unit time UE^{p}_{ijk} , and waiting energy consumption per unit time UE^{w}_{ijk} of each operation on m machine is given. The waiting time wt_{ijk} was determined by the completion time of the work piece and the start time of the next work piece on the same machine.

$$e^{total} = E_{process} + E_{wait} \tag{2}$$

$$E_{process} = \sum_{i=1}^{n}\sum_{j=1}^{l}\sum_{k=1}^{m} x_{ijk} \cdot UE^{p}_{ijk} \cdot t_{ijk} \tag{3}$$

$$E_{wait} = \sum_{i=1}^{n}\sum_{j=1}^{l}\sum_{k=1}^{m} x_{ijk} \cdot UE^{w}_{ijk} \cdot wt_{ijk} \tag{4}$$

Mathematically, an integer linear programming model of the FJSP was formulated as the following, which will be used throughout the paper.

$$\text{minimize Ztotal}=\{ \min\{t^{total}, e^{total}\}\} \tag{5}$$

Subject to:

$$\sum_{k\in M} x_{ijk} = 1,\ i = 1,2,...,n;\ j = 1,2,...,l;\ k = 1,2,...,m \tag{6}$$

$$x_{ijk} = \begin{cases} 1, \text{if machine } k \text{ is selected for operation} \\ 0, \text{otherwise} \end{cases} \tag{7}$$

$$e^{total} \le E_{\max},\ t^{total} \le T_{\max} \tag{8}$$

Where, Eq.5 is the objective function. Eq.6 ensures that each operation is assigned to only one machine from its candidate machine set. Eq.7 defines the assignment of procedures and the sequence of machines. Eq.8 guarantees that the production processed meet the constrains of makespan and energy consumption.

3. Heuristic Algorithm Considering the Adaptive Weight Adjustment Strategy

The heuristic algorithm based on the priority principle can produce acceptable scheduling results in a short period of time. The running time does not increase rapidly with the increase of the scale of the problem, and it is easy to implement. The workshop can timely obtain the production scheme, which adapts to the change of production status. In this paper, considering the global environmental pollution caused by the current manufacturing industry and the low-carbon production demand of the workshop, an integrated rule is constructed to improve the production efficiency rate based on the model of makespan and energy consumption. Firstly, according to this integrated rule, the machine tool is selected, and the FJSP problem is simplified to the traditional JSP problem, then the operation is determined.

In view of the production characteristics of flexible job-shop, the rule is composed of machine tool assignment and operation procedure schedule. Based on the adaptive adjustment strategy, the allocation results of each stage will affect the selection of the next stage. The details are as bellow.

machine tool assignment

In this paper, the greedy method is adopted for machine tool assignment. By combining the set of schedulable operations and scheduled operations, the makespan and energy consumption of each process can be selected to determine the minimum comprehensive index. First of all, make sure the operation is the first procedure, check the corresponding machine tool is used before, if so, the makespan and energy consumption should consider the completion time of machine tool, otherwise, get the makespan and energy consumption according to formulate (1), (2). If the operation is not the first procedure, it is necessary to comprehensively consider the completion time of the previous procedure and the completion time of the machine tool. The machine tool selection is determined according to the minimum integrated rule.

procedure selection

The corresponding machining process set and the current schedulable process set are comprehensively considered to construct the current schedulable process. The selection of the procedure is relatively simple compared with the selection of the machine tool, only the current processing situation is considered. The comprehensive index of schedulable process is calculated successively, and the minimum value is determined and selected.

adaptive adjustment weight

According to the assigned machine tool and procedure, the value of makespan and energy consumption in this case are calculated respectively. The two indexes are normalized and weighted to solve the comprehensive index value under the condition $Z^{total} = f_{norm}(e_{total}) + f_{norm}(t^{total})$. The average aggregation distance X=Ztotal/2 is taken as the mean of the two indexes. By calculating the deviation rate $S_{average} = \left(((Z_{total1} - X)^2 + (Z_{total2} - X)^2 + \ldots\ldots (Z_{totaln} - X)^2) \Big/ n \right)^{1/2}$ between the current two indexes and the average aggregation distance, the weight of the index is adjusted dynamically to shorten the gap between the index α,β and the average aggregation distance X, the assignment principle and processing priority of the next selection are adjusted to make the optimization result more reasonable. The specific process is as follows:

$$\alpha = \frac{f_{norm}(E_t) \cdot \left(1 + \left(S_{average} - f_{norm}(E_t)\right)\right)}{S_{average}} \tag{9}$$

$$\beta = \frac{f_{norm}(F_t) \cdot \left(1 + \left(S_{average} - f_{norm}(F_t)\right)\right)}{S_{average}} \tag{10}$$

4. Case Study

A case based on a mechanical workshop of completely flexible job shop was developed in order to verified the effectiveness of the model and algorithm. 5 work-pieces, 23 procedures are involved. The goal is to make a reasonable selection of the machine tool and processing sequence according to the integrate rule of the algorithm. The program was implemented in MATLAB 2010 on a computer with intel core i7, 2.39 GHz, 8 GB RAM, and a windows 8operating system. The production data are listed in table 1, 2, 3.

Table 1. Parameters in FJSP

machine tools	types	processing technology	idle power (kW)
M01	lathe	rough turning, finish turning	4.5
M02	lathe	rough turning, finish turning	9.4
M03	Grinding	grinding	7.5
M04	Milling	rough milling, finish milling	5.2
M05	Milling	rough milling, finish milling	8.4
M06	Milling	rough milling, finish milling	12

Table 2. Processing sequence of work-piece

number	processing sequence
P1	rough turning - rough milling - finish turning - finish milling - grinding
P2	rough milling - rough turning - finish turning - finish milling - grinding
P3	rough milling - finish milling - rough turning - finish turning
P4	rough milling - rough turning - finish turning - grinding
P5	rough turning - finish turning - rough milling - finish milling - grinding

Table 3. Processing parameters

	procedure	machines	time(min)	per unit energy consumption(kW)
P1	1	M01	3	14
		M02	2.5	30
		M03	1	60
	2	M04	3	14
		M05	2	30
		M06	0.3	50
	3	M07	3	10
		M08	2	16
		M09	1	30
	4	M10	3	11
		M11	2	16
		M12	1	35
P2	1	M01	1	58
		M02	4	16
		M03	2	42
	2	M04	3	10
		M05	1	27
		M06	0.5	62
	3	M07	5	9
		M08	1	15
		M09	0.5	40
	4	M10	3	7
		M11	2	12
		M12	1	35
P3	1	M01	4	15
		M02	1	20
		M03	0.6	60
	2	M04	3.5	12
		M05	3	17
		M06	2	35
	3	M07	5	14
		M08	2	16
		M09	1	55
	4	M10	2.5	11

		M11	2	21
		M12	1.1	40
P4		M01	1.5	17
	1	M02	2	20
		M03	1.2	60
		M04	3	15
	2	M05	2	21
		M06	1.2	56
		M07	2.5	11
	3	M08	1.5	20
		M09	0.8	40
		M10	3	12
	4	M11	1.4	30
		M12	3	16
P5		M01	4	20
	1	M02	2	18
		M03	1.5	60
		M04	3	17
	2	M05	1	20
		M06	0.25	45
		M07	4	16
	3	M08	2	17
		M09	1.4	62
		M10	1	46
	4	M11	5	13
		M12	3	16

In our work, 4 cases are proposed. Scheduling with makespan (case1), scheduling with energy consumption (case2), scheduling of time and energy consumption with fixed weight (case3), scheduling of makespan and energy consumption with adaptive weight (case 4). Through the operation of MATLAB program, the optimization results of four cases were obtained. The utilization rate of each machine tool corresponding to different cases was shown in figure 1. The optimization results of each case are compared and analyzed as follows.

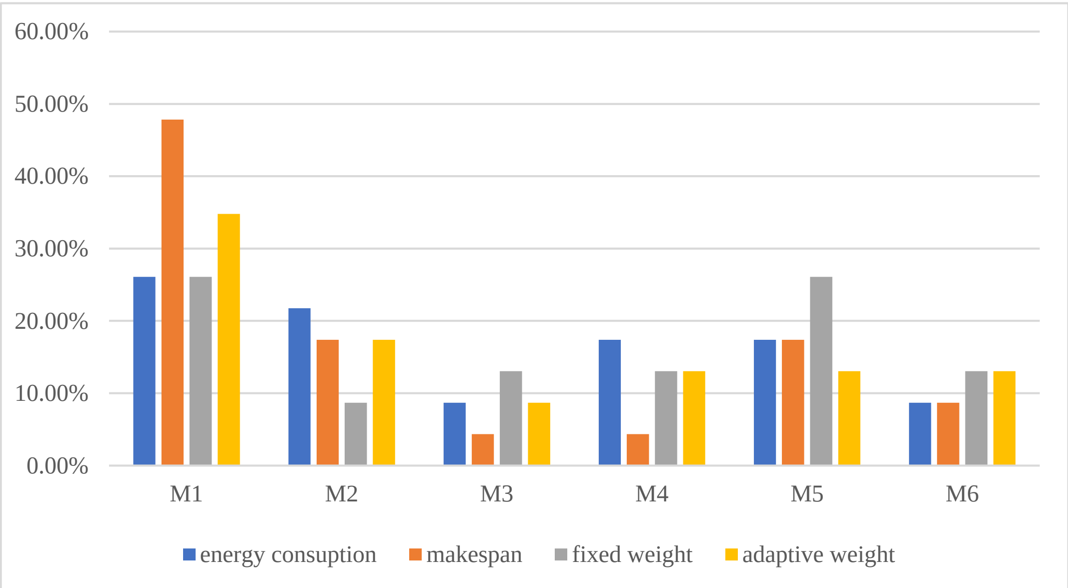

Fig 1. Utilization rate of machine tools

Table 4. The optimization results

Objectives	Case1	Case 2	Case 3	Case 4
makespan	13	20.5	18.6	17.35
Energy consumption	472.7	248	327	328.45

The results of the optimization of the indicators in each case are shown in the table. Cases 3 and 4 consider the sustainably scheduling. From Table 4, we can get: 1) optimal makespan was get in case 1, but the corresponding energy consumption is the largest. Case 3 saved 145.7 kW.h more than case 1, and case 4 saved 30.5% more than case 1; 2) case 2 obtains the optimal energy consumption, i.e., 248kW.h, but the corresponding makespan is consumed more than 1.9 min and 3.15 min compared with Case 3 and Case 4.

For case 3 and case 4, the value of makespan and energy consumption are between the values of Cases 1 and 2. As the integrated rule of scheduling, both makespan and energy consumption have alleviated the extremity of single-objective scheduling. Therefore, the optimization model proposed in this paper can make each optimization target compromise. On the other hand, case 4, which using the heuristic algorithm of adaptive adjustment strategy, the indexes accounting for 57.83% and 54.74% of the total value, the difference was about 3%. The index value of the fixed algorithm accounted for 76.6% and 56.81% of the total value, the difference was about triple than case 4. The adaptive adjustment weight index can be processed according to the result of the previous selection, and the weight of the next selection can be changed in time to make the operation result more balanced.

5. Conclusion

This work addressed an integrated rule based on the mathematical models, which firstly considered the correlation between the characteristic of objectives. The goal is to achieve FJSP sustainable production on the premise of production-efficiency, environment. The main contributions of this work were described as follows.

(1) A new multi-objective mathematical model for FJSP considering the makespan, energy consumption was developed. It can realize the sustainable production through the optimization of machines assignment and procedure sequence.

(2) A integrated rule based on the mathematical models, which was designed to intervene scheduling priority. It can achieve hierarchical optimization of workshop machine tools and processes. Adaptive adjusting the index weight coefficient by calculating the deviation rate between the index and the average aggregation distance, which can also guide the selection of machine tools and processes in the next stage and obtain a reasonable solution.

(3) A case study based on four cases were proposed to verified the effectiveness of the models and algorithm. The adaptive adjustment weight strategy can achieve the balance of makespan and energy consumption, the difference of each index is no more than 3%.

References

[1] Zhang R, Chiong R. Solving the energy-efficient job shop scheduling problem: a multi-objective genetic algorithm with enhanced local search for minimizing the total weighted tardiness and total energy consumption[J]. Journal of Cleaner Production, 2015, 112:3361-3375.

[2] Taisch M. Multi-objective genetic algorithm for energy-efficient job shop scheduling[J]. International Journal of Production Research, 2015, 53(23):7071-7089.

[3] LI Congbo, LI Pengyu, LIU Fei,et al. Multi-objective optimization model for machining process of high efficiency and low carbon[J]. Journal of Mechanical Engineering, 2014,17:133-141.

[4] Chirkin A M, Belloum A S Z, Kovalchuk S V, et al. Execution time estimation for workflow scheduling[J]. Future Generation Computer Systems, 2017:1-10.

[5] Bao B, Li T, Zhang B. Flexible job shop scheduling strategy with uncertain processing time[C]. International Conference on Mechatronics Engineering and Information Technology. 2017.

[6] Salido M A, Escamilla J, Giret A, et al. A genetic algorithm for energy-efficiency in job-shop scheduling[J]. International Journal of Advanced Manufacturing Technology, 2016, 85(5-8):1303-1314.

[7] LIOU C D, HSIEH Y C. A hybrid algorithm for the multi-stage flow shop group scheduling with sequence-dependent setup and transportation times[J]. International Journal of Production Economics, 2015, 170:258-267.

[8] ZHANG Chaoyong, LIU Qiong, QIU Haobo,et al. On flexible job-shop scheduling problem considering operation cost and time[J]. 2009, 28(8):1005-1011.

[9] Salido M A, Escamilla J, Giret A, et al. A genetic algorithm for energy-efficiency in job-shop scheduling[J]. International Journal of Advanced Manufacturing Technology, 2016, 85(5-8):1303-1314.

[10] LIU Aijun,YANG Yu, XING Qingsong,et al. Multi-population genetic algorithm in multiobjective fuzzy and flexible Job Shop scheduling[J]. Computer Integrated Manufacturing System, 2011,09:1954-1961.

[11] MIN D, TANG D, GIRET A, et al. Energy-efficient scheduling for a flexible flow shop using an improved genetic-simulated annealing algorithm [J]. Robotics and Computer-Integrated Manufacturing, 2013, 29(5):418-429.

[12] HE Y, LI Y, WU T, et al. An energy-responsive optimization method for machine tool selection and operation sequence in flexible machining job shops [J]. Journal of Cleaner Production, 2015, 87:245-254.

[13] TANG W H, YANG H D, LI Z T, et al. Non-identical Parallel Machine Scheduling Problem with Energy and Tardiness Cost[J]. Software, 2014.