FLEXIBLE JOB SHOP SCHEDULING PROBLEM OF MULTI-PROCESS PIPELINE AND BATCH MIXED PRODUCTION

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ABSTRACT: In view of current technical level of China’s manufacturing industry which needs to be improved in a long run, reasonable job shop scheduling (JSS) is an important measure to improve production efficiency at present. To this end, this paper summarizes the classification and existing problems of JSS problems. The results show that based on current status of multi-process pipeline batch-mixed production, new requirements have been put forward for the JSS study. Besides, a JSS model of multi-process pipeline was established, and the case analysis shows that the optimization effect of this model is superior to the traditional model; the JJS model of batch-mixed production was established, and the batch and non-batch schemes were discussed in the case analysis. Finally, it’s found that the batch-based scheduling can greatly improve production efficiency. This study can provide some reference and suggestions for the production and practice of manufacturing enterprises.

KEYWORDS: job shop scheduling (JSS), multi-process, pipeline, batch production.

1 INTRODUCTION

In today’s world economic integration, China’s manufacturing enterprises not only withstand the pressure of fierce domestic competition, but also bear the impact of advanced technology from the same industry around the world. The domestic manufacturing industry must continue to improve, so as not to be eliminated in the competition worldwide. China’s manufacturing industry has contributed a lot to the improved national production level (Figure 1), and its output value has increased year by year in recent years. Meanwhile, the proportion of China’s manufacturing industry in the global manufacturing industry also becomes higher, as shown in Figure 2.

In terms of the proportion of manufacturing alone, China has even surpassed developed countries such as the United States and Japan. However, from a technical perspective, China’s manufacturing level still has significant shortcomings compared with advanced European and American countries. The improvement of science and technology is not a one-off effort. It requires a relatively long-term process. Relatively speaking, under the constraints of limited manufacturing resources, it’s an effective “shortcut” to find a reasonable resource allocation method and improve production efficiency. For a better resource configuration, we need to conduct good production scheduling. Thus, under the limitation of insufficient resources, the resources can be fully utilized to ensure that production is completed in an orderly and timely manner.

The essence of the scheduling problem is to match existing resources with tasks that need to be
completed, in order to solve single-objective and even multi-objective optimization problems (Hu, 2015; Li et al., 2018; Shafransky et al., 2015). The resources referred to in the manufacturing industry usually include materials, machinery and equipment, energy, manpower, capital, etc. The JSS means the full use of resources and rational allocation of resources under certain constraints, so as to ensure the smooth operation of the entire manufacturing process (Qiao et al., 2014). JSS is often multi-objective. For instance, from the time perspective, the entire manufacturing period must meet the customer needs (Demir and İşleyen, 2014; Key, 2014); from a cost perspective, JSS must take into account the processing costs, storage costs, and possible costs incurred in the entire production process (Gao et al., 2014; Nguyen et al., 2015); from the perspective of machine tool use, the company cannot overload the machine; from the perspective of product quality, the workpiece must meet the performance requirements (Shen and Yao, 2015; Su et al., 2014). Therefore, it is of great significance to study the JSS problem.

2 JOB SHOP SCHEDULING

2.1 Classification of JSS problems

JSS is mainly a process of rationally configuring limited resources to achieve goal optimization. In the JSS process, it mainly involves the matching of tasks and resources, and is also constrained by time and goals (Abdullah and Abdolrazzaghezhad, 2014; Hosseinabadi et al., 2015; Shamshirband et al., 2015; Wang and Ming, 2014). Thus, the JSS problem can be classified from the four perspectives, as shown in Figure 3.

2.1.1 From the task perspective

The JJS problems are classified into:

a) Single machine scheduling problem: The single machine scheduling problem is a relatively simple one of the scheduling problems. The production of the workpiece has only one process, and the production of all the workpieces is performed on the same machine.

b) Parallel machine scheduling problem: The parallel scheduling problem is to replace the above single machine with a set of machines that can perform the same operation. The machining of the workpiece still has only one process, and the production of all workpieces is performed on one of the available machines.

c) Job shop scheduling problem: the production of workpieces is no longer limited to a single process, the function of the machine is no longer a single function, the processing routes are different from each other, and the production of each process needs to be specified on certain machine in advance, which is also unique. This model, as a simplified form of many practical problems, has very important research values and practical significance. Therefore, it is also one of the most widely used scheduling models in the research and application.

d) Flexible job shop scheduling problem: The difference between flexible job shop scheduling problem and job shop scheduling problem is shown in Figure 4. The circle in the figure represents the production process of the different parts, and the square represents the machine used in the production. The left side of Figure 4 represents the job shop scheduling problem, and the right side represents the flexible job shop scheduling problem. Figure 4 shows that the main difference between the two is that in the job shop scheduling problem, each process can only be carried out on a specific machine, and in the flexible job shop scheduling problem, each process may be on more than one machine. The flexible job shop scheduling problem is closer to actual production than job shop scheduling (Wang et al., 2015; Lei and Guo, 2014).

e) Flow shop scheduling problem: All workpieces have the same process, and the workpiece contains multiple processes; a set of machines with different functions is used for flow production.

f) Open shop scheduling problem: In the open shop scheduling problem, the process is performed in no particular order, but it can only be carried out on a specific machine.

g) Hybrid shop scheduling problem: In simple terms, the hybrid shop scheduling problem is a combination of the above two or more problems.

2.1.2 From the resource perspective

From the perspective of resources, the JSS problems are generally classified into single resource shop scheduling problems, dual resource shop scheduling problems, and multi-resource shop scheduling problems. These three are mainly determined by the resources that restrict production. If only one resource restricts production, it can be classified as a single resource shop scheduling problem; similarly, if there are two kinds of resources to restrict production, it can be classified into a dual resource shop scheduling problem; if there are more than two resources to restrict production, it can be classified as a multi-resource shop scheduling problem.
2.1.3 From the time perspective

The FFS problems can be classified into deterministic scheduling and uncertainty scheduling. The difference between the two is whether the parameters of processing time are clear.

2.1.4 From the objective perspective

It can be classified into single-objective scheduling and multi-objective scheduling. The difference between the two is the different number of optimization objectives.

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**Fig. 3 Time scheduling problem classification**

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**Fig. 4 Flexible job shop scheduling and job shop scheduling**

2.2 Existing problems in JSS research

The research on traditional JSS problem has achieved quite fruitful results. However, some problems in actual production have brought new challenges to the JSS research.

In the study of JSS problems, for the sake of convenience, researchers often propose a series of assumptions, for example, each workpiece must be machined on a specified machine; a clear process flow must be given before the workpiece processing; for different types of workpieces, the process design also varies; the specific machine at the moment can only be used for the same part. In fact, these assumptions are far from actual production. In modern manufacturing, there can be more than one process route for each part, and each process can be completed with different tools. That is, the current status of multi-process pipeline production in the manufacturing industry challenges the traditional research conducted under the assumptions.

Besides, in the traditional JSS problem research, it is usually assumed that the processing of parts is for the entire batch of parts, and in the actual manufacturing process, the processing of parts is often performed according to a more detailed sub-batch. The production and processing of parts in sub-batch can effectively improve the utilization of resources, and reduce the idleness and waste of machine tools, which has very important application value and significance.

In summary, if the JSS problem in multi-process pipeline and mass production can be solved, it will certainly promote the progress of China's manufacturing industry in a positive manner.
3 FLEXIBLE JOB SHOP SCHEDULING FOR MULTI-PROCESS PIPELINE AND BATCH MIXED PRODUCTION

3.1 Mathematical model

This paper mainly uses flexible JSS model to solve multi-process problems and batch mixed production problems. In this paper, model I was established for multi-process problems, and model II was established for batch mixed production problems. The assumptions for the two models are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Model assumptions</th>
<th>Model hypothesis</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uninterruptible</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Unique machine</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Unique artifact</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Independent artifact</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process sequence</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing time of each process is determined</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batch startup time determination of workpiece</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The machines are idle when machining starts</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
</tbody>
</table>

As shown in Table 1, both Model I and Model II assume that the manufacturing process is coherent, that is, the entire process is not interrupted; at the same moment, a single machine can only be used to produce a single workpiece, and also a single workpiece is only be produced on the same machine; at the beginning of the process, the machine is idle, that is, in the early stages of production, the machine is ready to be put into production at any time. In addition, Model I also assume that the process is independent and ignores the time wastage between the processes; Model II assumes that the start time and processing time of the process are determined.

Model I takes the shortest production cycle as the optimization goal, and the objective function is as follows:

\[ m_1 = \max \left\{ L_{ikjl} \mid 1 \leq i \leq N, 1 \leq k \leq G_i \right\} \]

It satisfies all:

\[ L_{ikjl} = S_{ikjl} + T_{ikjl} \]

\[ L_{ik(j-1)l} \leq S_{ikjl} \leq L_{ikjl} \]

\[ G_i \geq 1, G_{ik} \geq 1 \]

where, i, k, j, l are the number of the workpiece, process route, process and machine, respectively; \( L_{ikjl}, S_{ikjl}, T_{ikjl} \) respectively represent the completion time, the starting time, and the processing time of the workpiece i in the jth process of the kth process route on the machine l; N is the number of workpieces; M is the number of machines.

Model II also takes the shortest production cycle as the optimization goal. The objective function is as follows:

\[ m_2 = \max \left\{ L_{izjl} \mid 1 \leq i \leq N, 1 \leq z \leq Z, 1 \leq j \leq J \right\} \]

It satisfies both:

\[ L_{izjl} = S_{izjl} + T_{izjl} \]

\[ L_{iz(j-1)l} \leq S_{izjl} \leq L_{izjl} \]

where, i, z, j, l represents the workpiece, batch number and process, respectively.

3.2 Case analysis and effect comparison

The solution to the above model is complex. The conventional mathematical methods often fail to produce satisfactory results. In this paper, the genetic algorithm was used to solve the model. Compared with the traditional mathematical methods, the stability and efficiency of the genetic algorithm are greatly improved, which is worthy of promotion and application. The solution process of the genetic algorithm is shown in Figure 5.

![Figure 5. Genetic algorithm flow chart](image-url)
The genetic algorithm parameters were set, as shown in Table 3.

<table>
<thead>
<tr>
<th>Population size</th>
<th>Cross probability</th>
<th>Mutation probability</th>
<th>Maximum number of iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.85</td>
<td>0.05</td>
<td>50</td>
</tr>
</tbody>
</table>

In this paper, the mathematical model I of multi-process pipeline operation and the traditional job shop scheduling problem model were solved respectively. Table 4 compares the target optimization of the two models.

<table>
<thead>
<tr>
<th>Production time</th>
<th>Model I</th>
<th>Traditional model</th>
</tr>
</thead>
<tbody>
<tr>
<td>77</td>
<td>119</td>
<td></td>
</tr>
</tbody>
</table>

It can be seen from Table 4 that the model I is significantly superior to the traditional model.

### 3.2.2 Batch mixed shop scheduling problem

Case background: There are 4 kinds of workpieces in the total batch size of 12, and the workpiece process is determined, as shown in Table 5.

<table>
<thead>
<tr>
<th>Number of the components</th>
<th>Machine and time</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(3,5)→(2,4)→(1,4)</td>
</tr>
<tr>
<td>B</td>
<td>(4,7)→(2,9)→(1,3)</td>
</tr>
<tr>
<td>C</td>
<td>(3,2)→(1,9)→(2,3)</td>
</tr>
<tr>
<td>D</td>
<td>(2,3)→(1,2)→(4,5)</td>
</tr>
</tbody>
</table>

In this paper, the workpieces were divided into two batches, three batches and four batches, which was compared with the non-batched scheme. The results are shown in Figure 6.

### 4 CONCLUSIONS

1. This paper summarizes the problems existing in the research of JSS problems, and finds that the assumptions used in the previous research have made great difference from the current multi-process pipeline production mode and batch-mixed production mode. Therefore, it is necessary to re-establish the model for research;

2. A multi-process pipeline shop scheduling model was established and the model using genetic algorithm was solved. After the solution, compared with the traditional JSS model, it’s found that the multi-process flow shop scheduling model...
established in this paper has more advantages in target optimization;

(3) A batch-mixed production JSS model was established. In the case analysis, the schemes with batches 2, 3, 4 were compared with the batch-free scheme. It was found that the batch-based scheme was significantly more advantageous in improving production efficiency, so as to effectively shorten the production cycle.

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6 REFERENCES


