Flexible Assembly Job Shop Scheduling Based on Tabu Search

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Abstract

Flexible assembly job shop scheduling has been proved to be an NP-hard problem. To reduce the complexity, it is always divided into 2 sub-problems: routing sub-problem and sequencing sub-problem. In this paper, in order to develop a solution with high accuracy, we propose a method that can deal with these two sub-problems concurrently. Tabu search, one of the meta-heuristics, is adopted. Some experiments are made to seek the best way to exchange the routes & sequences of work (operation) pairs in order to improve the result of schedule. Also some experiments of how to make a tabu list to identify the repetitive trials on the same work pairs are made too. The effect of our algorithm on decreasing total delay behind due time is confirmed.

1. Introduction

In a flexible assembly shop (FAS), work-cells, which consist of machines and/or workers, are set instead of lines because work-cells are more capable of coping with frequent changes in production parameters (ex. quantities, types etc.). The characters of work-cells can be described as follows:

(1) Each work-cell is multi-functional, which means alternative route can be chosen.
(2) Work-cells differ very much in process capability (ex. processing time etc.).

Furthermore, in this kind of shop, there are various jobs including a large number of operations with their process precedence. So one of the problems is that too much time is spent in waiting for the precedent operations to be finished. Especially when short lead-time is required, it is important to plan the completion timing of the operations that have parallel precedence relationships, so that the next operation can be done without waiting time.

Therefore the scheduling which is to assign jobs' operations to work-cells, and to determine the sequence of operations at each work-cell becomes a huge scale and complicated problem.

Over the past few decades, a considerable number of studies have been made on the scheduling problem of flexible manufacturing system (FMS), but many of them only dealt with the machining systems. (Ex. [1][4][7][8][10] etc.)

The difference between a flexible assembly job shop scheduling and a flexible machining job shop scheduling is clarified by Markus Donath[6] . The FAS scheduling problem is proved to be NP-Hard and is more complicated than the classical job shop scheduling problem. Thus, while we review the previous literatures, we found that only a few simple approaches were proposed to solve the FAS scheduling problem: for example, rules based on experience such as dispatching rules (see [3][11]), and simple improvement methods like literature [2]. Furthermore, in order to reduce the complexity of the problem, it is common to decompose the original problem into two sub-problems, routing sub-problem and sequencing sub-problem. When the routing sub-problem alone is taken up, the flexible assembly scheduling problem turns into the classical job shop problem.

But we should notice one point that the difference in capability between work-cells turns out to be small in the above researches while in real flexible assembly workshops it is very big because of the composition of work-cells. If we employ the above approaches, the function of load balancing and minimization of orders' delay behind due time are not compatible. So the approach based on the idea of decomposition is inferior in accuracy. The routing problem and the sequencing problem must be dealt with concurrently in a flexible assembly shop.

In order to develop a solution with high accuracy, we adopt the idea of tabu search, one of the meta-heuristics, which has been shown to have the high possibility to get a good solution. We propose an algorithm based on tabu search to solve routing and sequencing sub-problems concurrently (detail in chapter 3).

2. Problems Statement

2.1 Order (job)

- Order: Order also can be called ‘job’ or ‘product’. A job consists of more than one unit of operation.
- Operation: Operation is a process to joint parts.
- Part: Part is a unit of a product. It can also be called ‘component’.
- Assembly sequence: Assembly sequence is not fixed: more than one assembly sequence can be selected because of the existence of parallel precedence relationship.

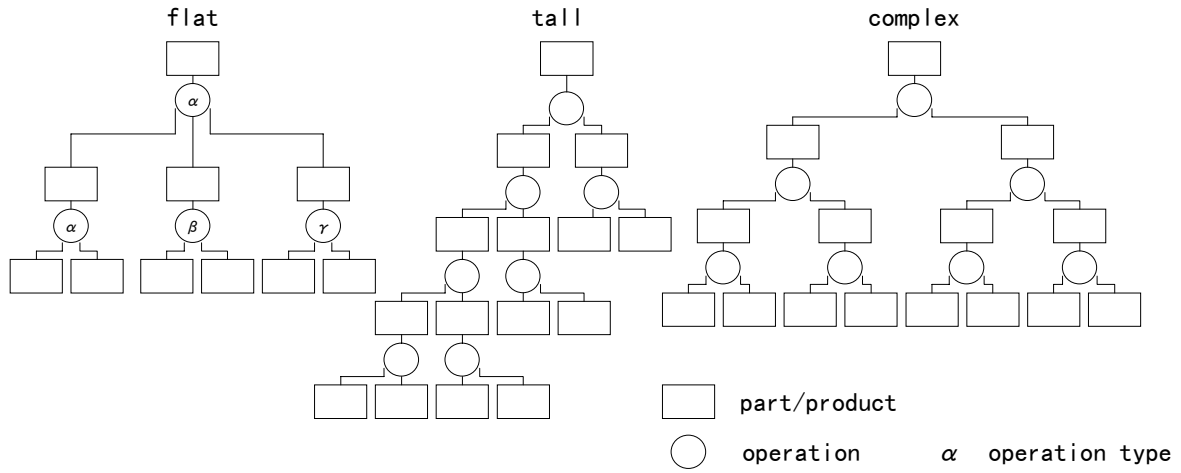

Fig.1 Job structures

2.2 Work-cell (W/C)

- Work-cell: Work-cell is composed of, either short lines, one/plural machine(s), one/plural worker(s), or the combination of machines and workers.
- Machine: Machines in a work-cell can be special-purpose machines or general-purpose machines, automatic or manual.
- Worker: Workers who work in a cell can be new or skilled ones. They can deal with one or more than one type of operation.
- Process ability: Each work-cell can deals with more than one type of operation, and the difference in processing time between work-cells is very big.

2.3 Scheduling Function

In this paper, scheduling means to decide work places and process sequences of all the jobs/ operations. The purpose of it is to minimize the total delay of jobs behind due time. Thus the function can be formulated as follows:

Function: Minimize $\sum_{i=1}^{n} DT_i$ (1)

(if $LT_i > D_i$ $DT_i = LT_i - D_i$, if $LT_i <= D_i$ $DT_i = 0$)

Where

DT_i: delay of job i behind due time,

LT_i: lead-time of job i,

D_i: due time of job i.

As the lead-time of a job is composed of processing time (PT), changeover time (CT), waiting time for operation sequence (WST), waiting time for precedence operation (WPT) and transport time (TT), the function can also be converted to below:

$$\text{Minimize } \sum_{i=1}^{n} (PT_i + CT_i + WST_i + WPT_i + TT_i) \quad (2)$$

3. Proposed Algorithm Based on Tabu Search

Reviewing the past literatures concerning tabu search, we find that only process sequences of jobs/operations were exchanged and their routings are not examined during the search. As we have pointed out in chapter 1, it is important to consider the routing and sequencing sub-problems concurrently, so that here we propose an algorithm based on tabu search (local search) which can deal with these two sub-problems at the same time.

At first, an initial solution is given. Then the initial schedule is obtained and going to be refined by tabu search with the fellow procedure.

Through the initial solution, each operation is given:

- a possible processing start time,
- a machine number that indicates the place where it is processed,
- a sequence number that indicates its process turn.

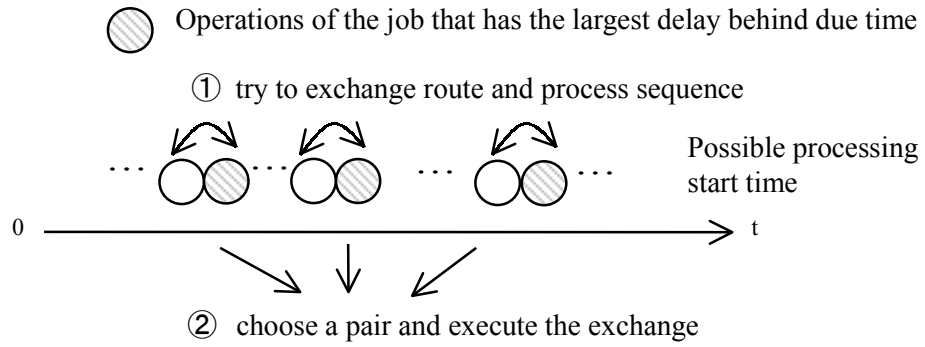

Fig.2 The procedure of operations' exchange

Also each job's delay behind due time can be calculated based on the initial solution.

Then, a job is chosen (we will mention the selection ways later) and attempts are made to re-route and re-sequence all of its operations, tentatively making pairs of operations so that one pair consists of two operations whose start times are next to each other, and exchanging their routes and process sequences one pair after another (see figure 2).

The pair that, when the above exchange is made, can decrease the total delay behind due time most efficiently is selected, and the exchange is definitively executed on the selected pair.

The time given to this trial for improvement is determined in advance. And a tabu list is given to avoid repetitive trials on the same pair of operations.

[Ways of selecting a job as an object of improvement]

(1) choose the job with the largest delay behind due time
(2) choose the job with the longest waiting time among the jobs that are assigned to the machine which has the longest idle time
(3) choose a job randomly

[Tabu list]

A tabu list contains the following items in order to identify the repeated search on the same pair of operations: the machines that they have been assigned to, the process sequences on those machines and the process start times. All the pairs on the list are checked before the exchange is executed.

A tabu list for jobs is also made to avoid repetitive trials on the same job. When continuous search on the same job exceeds K times (K= the number of times that has been fixed in advance), the job is listed on the tabu list.

4. Evaluation

4.1 Ways of Selecting a Job

We proposed 3 ways of selecting a job. They are evaluated by the total delay behind due time. Comparing figure 3 and figure 4, we can see that selecting a job randomly can decrease the total delay behind due time largely if it is given enough time, because this way of searching can cover wider scope. But, when efficient improvement is required, the other two ways of selecting a job are more useful because they consider the causes of delay.

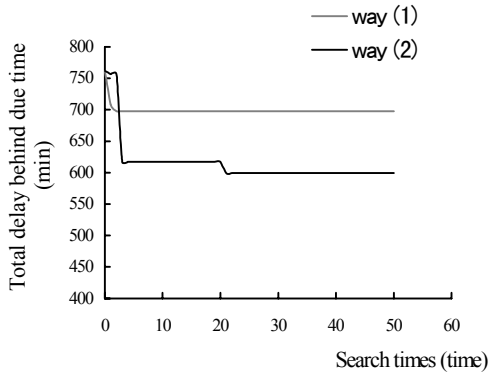

Fig.3 Selecting a job according to certain criteria

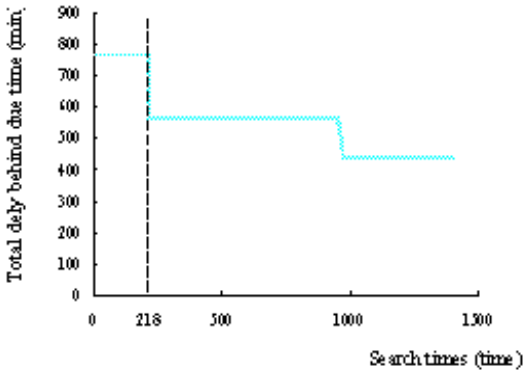

Fig.4 Random job selection

4.2 Initial Solution

All the above experiments are made with the initial solution obtained by a heuristic algorithm based on the ideas of grouping operations and dealing with routing & sequencing sub-problems concurrently in order to decrease the changeover time, processing time and waiting time [5] (we call it method (1) later). Here some initial solutions obtained by simple heuristics using dispatching rules are also examined (method (2)).

Figure 5 shows the difference between the improvement results of the above 2 methods, the dispatching rules used here are as follows: STPT (Shortest Total Processing Time) rule for routing and EDD rule for sequencing

There are two vertical axis in figure 5, both of which show the total delay behind due time (min); the left one is for the improving result of the initial solution obtained by method (1), and the right one is for the initial solution obtained by method (2). The diagram shows that the result of improvement using the proposed improving algorithm by tabu search (local search) is influenced by the initial solution. In order to get a quasi-optimized solution in a limited time, a good initial solution is helpful.

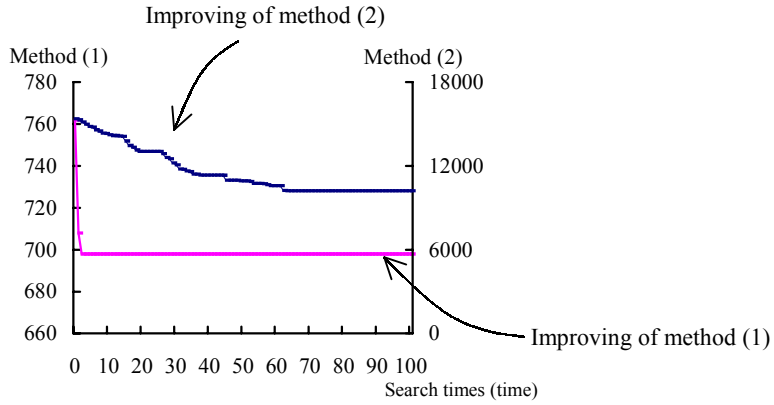

Fig.5 Influence of initial solution on improvement

4.3 Accuracy of proposed algorithm

We also compared our algorithm with the exact algorithm under the condition that the scale of problems is small enough for the strict solution to handle, the accuracy is confirmed.

5. Conclusion

In this paper an algorithm based on tabu search is proposed. Some items concerning tabu search, such as how to select a target job and how to make a tabu list are tested. The ways of selecting a job considering the cause of delay are proved to be effective in improving the solution. The effect of the proposed algorithm on decreasing total delay behind due time is confirmed. And it is cleared that a good initial solution for the proposed algorithm is required in order to improve the solution efficiently.

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