DUE-DATE CONFORMANCE-ORIENTED SCHEDULING METHOD ALLOWING SMALL LOT-SIZE JOB INTERVENTION

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ABSTRACT

Aiming at an excellent schedule with respect to due-date related criteria, a scheduling method is proposed which allows the intervention of a small lot size job into the large lot size job processing assignment in the schedule. In order to realize the intervention, it is necessary to determine the jobs and the timings to intervene. We propose a scheduling procedure which generates a solution by using the parameter-space-search-improvement (PSSI) method. We first introduce three parameters to determine the jobs and the timings to intervene, and propose a scheduling procedure in which GA is adopted to obtain an initial schedule which contains only the large lot size jobs. A search procedure to obtain an excellent schedule is then described, and finally the performance of the proposed method is investigated on a simple flow shop model.

INTRODUCTION

In a recent severe and competitive economic environment, the variety of the required product becomes diverse and the number of final product specified by each order ranges from a few to many, which makes the production planning and scheduling more difficult than before to meet the customer due-date for each order. When the customer order is transformed to job to produce the specified product, the job associated with small quantity to produce (we shall call it a small lot size job, hereafter) requires special consideration, since the slack time supposed for such a job is smaller than that for large lot size jobs.

In order to meet the due-date for a small lot size job, it is required in scheduling to avoid a small lot size job to be a work-in-process job due to the long occupation of the machine by a large lot size processing. On the shop floor, the processing operation for a small lot size job is sometimes allowed to interrupt and to intervene the long processing for a large lot size job when it is judged to make sense to prevent the above mentioned long waiting time. (We shall call this action “the intervention of a small lot size job”, hereafter.) It is expected to suppress small lot size jobs to become tardy if such an intervention is considered in a scheduling procedure.

In this paper, we propose a scheduling method which aims to generate an excellent schedule with respect to due-date related criteria by considering the intervention of a small lot size job in the scheduling procedure.

In order to realize the intervention, it is necessary to determine the jobs and the timings to intervene. In a realistic problem, it is practically impossible to obtain an optimal solution as a combinatorial problem. We propose a scheduling procedure which generates a solution by the parameter-space-search-improvement method (named the PSSI method) (Fuyuki et al. 1998) in which a Genetic Algorithm (GA) is used. The PSSI method is a framework for finding the best solution in a simulation method. It introduces a very few number of parameters which can systematically manipulate the relevant variables and the best solution is sought for on the parameter space spanned by the introduced parameters. It can give an excellent solution in a practical sense if pertinent parameters are adopted.

In this paper, we first introduce three parameters to determine the jobs and the timings to intervene, and propose a scheduling procedure in which GA is used to obtain an initial assignment of the large lot size jobs, and describe a search procedure to obtain an excellent schedule. Finally, the performance of the proposed method is investigated on a simple flow shop model.

PROPOSED SCHEDULING METHOD

In order to obtain the due-date conformance-oriented schedule, the proposed scheduling method adopts the best parameter search procedure which involves job classification and schedule generation procedure. One parameter is introduced to classify jobs into small and large lot size jobs, and two parameters are used to estimate the 'earliest possible operation-intervention time' for a small lot size job in the schedule generation procedure.

Parameter to classify jobs

We divide whole jobs into two groups according to their lot size. We regard the ratio of the number of jobs classified to small lot size jobs over the total number of jobs as the parameter denoted a. In a practical situation, it may not need to classify the jobs by such a parameter, since the job can be classified according to a certain practical reason whether it can be interrupted or not. However, in this study we introduce this parameter to investigate the characteristics of the proposed

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method on a simple model.

**Parameters to use for job intervention**

We estimate the earliest possible operation-intervention time for the j-th operation of a small lot size job i by

\[
ST_{j,i}^{\text{mod}} = ST_{j,i} - \{\alpha L + \beta (W_j + \Delta ST_{j-1})\}, \quad (1)
\]

\[
\Delta ST_{j,i} = ST_{j,i} - ST_{j,i}^{\text{mod}}, \quad (2)
\]

\[
\Delta ST_{j,i} = 0, \quad (3)
\]

\[
W_j = ST_{j,i} - r_i, \quad (4)
\]

where \(ST_{j,i}\) and \(W_j\) stand for the operation onset time and the waiting time for the j-th operation of a small lot size job i, respectively, and \(L\) stands for the tardiness of job i, all in the initial configuration schedule explained in the next section, and \(r_i\) is the release time of job i. In Eq. (1), we introduce two parameters \(\alpha\) and \(\beta\) in order to systematically control the timings of the operations of all small lot size jobs to intervene according to the characteristics of their assignment in the initial configuration schedule. Figure 1 illustrates the intervention and the variables for a simple two machines flow shop model.

**Schedule generation procedure**

The schedule generation procedure takes the following steps:

1) Generation of an assignment of large lot size jobs. A GA method is used to obtain the assignment result which maximizes the sum of due-date minus completion time of every job. The Giffler-Thompson method is used for the assignment of all jobs to machines in the process of the GA method.

2) Using the SLACK rule, the small lot size jobs (the operations of which are indicated by the crosshatched boxes in Figure 1(a)) are assigned on each machine by appending to the large lot size jobs in order to form a schedule which we shall call an ‘initial configuration schedule’.

3) The earliest possible operation-intervention time for a processing operation of a small lot size job is estimated for all operations of all small lot size jobs based on the assignments of the initial configuration schedule and by using the two parameter values. (\(ST_{1,i}^{\text{mod}}, ST_{2,i}^{\text{mod}}\) in Figure 1(a).)

4) Every large lot size job is disintegrated to ‘unit’ jobs each of which produces a single piece of the original lot. Furthermore, the starting time of a single piece processing operation is preserved as the ‘earliest possible operation-onset time’ for corresponding unit jobs on each machine. (Blank and gray boxes in Figure 1 indicate the operations for unit jobs.)

5) Imposing the estimated earliest possible operation-intervention times and the earliest possible operation-onset times as scheduling constraints and using the chronological order of those times as priority order at dispatching, a forward simulation for all jobs is executed to obtain a schedule where

![Diagram](image-url)

(a) Initial configuration schedule

(b) Schedule modified by job intervention

**Parameter search procedure**

In order to obtain the due-date conformance-oriented schedule, the best parameter search procedure is adopted. We need to search parameter space spanned by three parameters \(\alpha\), \(\beta\) and \(\gamma\) for the set of parameter values which give the best schedule with respect to the objective function.

We adopt the enumeration method for the parameter \(\alpha\) and the pattern search method (Hooke and Jeeves, 1961) for the parameters \(\beta\) and \(\gamma\).

**EVALUATION OF PROPOSED METHOD**

In order to evaluate the performance of the proposed method, we adopt a flow shop model, since the waiting time of small lot size jobs can be controlled by the initial condition and the job completion time is expected to be affected significantly by the job intervention. The adopted model is too limited to
obtain comprehensive understanding of the performance of job intervention in a production scheduling and some assumptions such as equal processing times for unit job are unrealistic, but they are selected here to show clearly the characteristics of the proposed method.

Model
The model adopted is a simplified flow shop model with 3 machines and n jobs. We set the following conditions on the model:

- Each job must go through all the different machines.
- Six lots sizes from 1 to 6 are assumed for the jobs, and set the number of jobs equal for each lot size.
- The processing time of all unit jobs is set to be 60 at every machine.
- The changeover time to setup for the subsequent different job operation is set to be 30 (half of the processing time for unit job).
- The jobs are release to the shop according to the descendant order of their lot sizes.
- The release time of the i-th released job is determined by Eq.(5) using the “release time coefficient” $k_r$.

$$r_i = r_{i-1} + k_r \left( \sum_{j=1}^{i-1} p_{ij} - r_{i-1} \right)$$

$$r_0 = 0$$

Here, $p_{ij}$ denotes the processing time of job $i$ at machine $j$.
- Due-date $d_i$ of job $i$ is determined by Eq.(7) using the “due date coefficient” $k_d$:

$$d_i = k_d \sum_{j=1}^{i} p_{ij} + r_i$$

- The average tardiness $\bar{L}$ is adopted as a criterion for simplicity. It is noted that more sophisticated criterion such as the weighted tardiness can be used without modification in the proposed method.

Numerical Condition
We set the following numerical conditions to apply the proposed method to the present model.

1. GA method
   In applying GA method, the number of chromosome is set to 100, crossover ratio to 80%, mutation ratio to 50% and the number of searching to 10000.

2. Parameter values in the parameter search procedure
   As for the parameter $\alpha$ and $\beta$, the initial values are set to 1.0, the initial width to 0.1, and the minimum width to 0.05. On the other hand, the parameter ‘$\alpha$’ is set from 0 to 0.5 with the increment of 0.1.

Methods adopted for comparison
In order to evaluate the performance of the proposed method, three scheduling methods are adopted which treat the jobs in different ways, but all use GA method.

(Method 1) A scheduling method which uses the same GA method as used in the proposed method treating all jobs without job intervention. This method is equivalent to the proposed method under the condition $\alpha = 0.0$.

(Method 2) Contrary to the Method 1, every job is disintegrated into unit jobs keeping the original due-date for each unit job, and the best schedule is obtained by the GA method. All disintegrated unit jobs are regarded as different jobs in the assignment process. The average tardiness of the schedule is calculated by using the completion times of every last pieces of the unit job belonging to the same original job.

(Method 3) A scheduling method proposed by Kanezashi and Mitani (2002). This method applies the GA method to the jobs disintegrated by the specified number. The maximum number that can disintegrate each large lot size job into small lot size jobs is used as the specified number, and it estimated by the changeover time and the slack time between due-date and the complete time of the job in the schedule generated by Method 1.

The number of search is set to be 100,000 for all three methods, since it gives sufficient calculation time to obtain the optimal solution.

Effectiveness of the proposed method to reduce the average tardiness
Table 1 shows the number of jobs, n, and the due date coefficient and the release time coefficient used for numerical experiments. Different values are adopted for the problem with different number of jobs. This is because that the waiting time of small lot size jobs depends on the number of jobs due to the occupation of machines by large lot size job processing operation. Table 2 shows average tardiness of schedules generated by different methods. The asterisk * in the table indicates the result which is judged not to achieve the optimal solution from the time transition of the results.

Since the proposed method includes the scheduling procedure of Method 1 as one particular case of the parameter set, the result of the proposed method is expected to be the

<table>
<thead>
<tr>
<th>n</th>
<th>6</th>
<th>24</th>
<th>48</th>
<th>96</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_r$</td>
<td>0.2</td>
<td>0.05</td>
<td>0.025</td>
<td>0.0125</td>
</tr>
<tr>
<td>$k_d$</td>
<td>1.4</td>
<td>2.8</td>
<td>5.6</td>
<td>11.2</td>
</tr>
</tbody>
</table>

Table 2. Comparison of average tardiness of schedules generated by different methods.

<table>
<thead>
<tr>
<th>n</th>
<th>Proposed method</th>
<th>Method 1</th>
<th>Method 2</th>
<th>Method 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>220.0</td>
<td>270.0</td>
<td>202.8</td>
<td>212.0</td>
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<tr>
<td>24</td>
<td>654.0</td>
<td>681.2</td>
<td>796.7</td>
<td>729.7</td>
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<tr>
<td>48</td>
<td>920.4</td>
<td>971.4</td>
<td>1638.0*</td>
<td>1218.0*</td>
</tr>
<tr>
<td>96</td>
<td>1706.6</td>
<td>1883.6</td>
<td>3354.0*</td>
<td>2310.0*</td>
</tr>
</tbody>
</table>

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same or superior than that of Method 1. Comparing the result of the proposed method with that of Method 1, we can estimate the effectiveness of the job intervention control in the proposed method. From the table, the reduction of average tardiness attains between 5% and 18% of the value in schedules generated by Method 1.

In the case n=6, Method 2 and 3 give superior schedule than the proposed method, but the proposed method gives superior schedule as the number of job increases. The optimal solutions have not been obtained by Method 2 and Method 3 for the cases n>24. This indicates that it is difficult for Method 2 and 3 to search for the optimal solution when the number of jobs involved is large. Disintegration of large lot size jobs into small lot size jobs leads to the serious increase of the number of jobs to handle in the scheduling process.

The elapsed time required for the proposed method is 12.8(min) for even for the case n=96 on the computer with Pentium4, 2.0GHz CPU. It is clear that the assignment of large lot size jobs without disintegration in the proposed scheduling method saves the calculation time. This is a significant advantage of the proposed method in practical use.

From the properties of flow shop, the effectiveness of job intervention depends on the relation between release time and due-date for reduction of average tardiness. We can control the waiting time of small lot size jobs due to occupation of machines by large lot size job processing and due-date tightness of a schedule by due-date of each job in initial condition. In this part, we investigate the effectiveness of job intervention procedure and the performance of parameter control under different conditions of release time and due-date. Table 3 shows the difference $\Delta L$ between average tardiness obtained by the proposed method and that by Method 1.

These results are calculated under the conditions that release time coefficients $k_i$ are set to be 0.2 or 0.6. The number in the parentheses indicates the ratio of the difference to average tardiness of the schedule generated by Method 1. The distributions of the difference take the convex shape with respect to the due-date coefficient.

It illustrates that the condition to attain the maximum effectiveness of job intervention procedure exists in the range of due-date tightness on the table. Asterisks * in the tables indicate such conditions. By increasing the release time coefficient $k_i$, the effectiveness of job intervention measured by $\Delta L$ decreases and the due-date coefficient $k_d$ which gives the maximum effectiveness shifts to smaller value. The values of three different parameters have been changed. The result in the table indicates that the job intervention can be controlled effectively by using the proposed parameters to reduce the tardiness of jobs.

Moreover, parameter ‘a’ is found to significantly affect the result at different conditions. It indicates that the classification of all jobs into two types of jobs, large lot size jobs and small lot size jobs, is necessary to control job intervention.

### Table 3. Average tardiness differences and parameter values yielding the best solution by the proposed method. (The numbers in parentheses are in %)

<table>
<thead>
<tr>
<th>$k_d$</th>
<th>1.0</th>
<th>1.2</th>
<th>1.4*</th>
<th>1.6</th>
<th>1.8</th>
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<tbody>
<tr>
<td>$\Delta L$</td>
<td>20.0</td>
<td>28.0</td>
<td>32.0</td>
<td>22.0</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>(4.56)</td>
<td>(8.24)</td>
<td>(13.5)</td>
<td>(16.2)</td>
<td>(11.8)</td>
</tr>
<tr>
<td>$a$</td>
<td>0.33</td>
<td>0.17</td>
<td>0.33</td>
<td>0.33</td>
<td>0.17</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.10</td>
<td>0.00</td>
<td>0.15</td>
<td>0.15</td>
<td>0.00</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.95</td>
<td>1.00</td>
<td>0.80</td>
<td>0.80</td>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$k_d$</th>
<th>1.0</th>
<th>1.2</th>
<th>1.4</th>
<th>1.6</th>
<th>1.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta L$</td>
<td>20.0</td>
<td>27.0</td>
<td>20.0</td>
<td>19.0</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>(6.9)</td>
<td>(12.7)</td>
<td>(13.7)</td>
<td>(23.8)</td>
<td>(29.8)</td>
</tr>
<tr>
<td>$a$</td>
<td>0.50</td>
<td>0.50</td>
<td>0.33</td>
<td>0.50</td>
<td>0.33</td>
</tr>
<tr>
<td>$\alpha$</td>
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<td>0.75</td>
<td>0.35</td>
<td>0.80</td>
<td>0.05</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.95</td>
<td>0.40</td>
<td>0.60</td>
<td>0.75</td>
<td>0.90</td>
</tr>
</tbody>
</table>

### CONCLUSION

Aiming at a due-date conformance-oriented scheduling, we proposed a new scheduling method which allows the intervention of a small lot size job operation into the large lot size job processing assignment. The PSSI method is used in the scheduling procedure in which a GA method is adopted to generate the initial configuration schedule. The performance of the proposed method is evaluated by the numerical experiment with a simple flow shop model. The results of the experiment show that the control of job intervention is effective in reduction of the average tardiness of the schedule.

Furthermore, the proposed method is found to generate superior schedules in a short calculation time than those obtained by conventional GA methods. The major parts of elapsed time required for scheduling in the proposed method is spent on the calculation by GA method involved, and therefore it is worth while to investigate to use a possible alternative optimal scheduling method to reduce the calculation time.

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