A Heuristic Solution Method of Mixed Problem of Materials’ Cutting Plan Decision and Production Scheduling for Foundation Reinforcement Units Manufacturing

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Abstract: In recent years, the Base Reinforcement System (BRS) has been developed and applied widely at building sites to improve the productivity of building operations and reduce the waste of materials. Because of customers’ orders with a wide variety of specifications and very short delivery times, it is necessary to achieve efficient production of foundation reinforcement units. In this study, we consider the practical production planning problem in a foundation reinforcement unit manufacturing factory, and propose a heuristic solution method to solve the mixed problem of materials’ cutting plan decision and production scheduling. According to our computing experiment result, we can demonstrate that the method proposed in this paper can consider multiple orders simultaneously, decide the best cutting plan to improve the yield rate of materials, and meanwhile it can also obtain better production schedules with shorter makespan and less variation.

Key Words: Production planning, Scheduling, Base Reinforcement System (BRS), Cutting stock problem, Bin-packing problem, Simulated annealing.

1. Introduction

As society ages and birth-rate falls, it has become a difficulty issue to secure skilled human resources for almost every industry. The housing industry faces also the issues of aging of the labor force and shortage of skilled workers, while customers’ diversified needs have to be responded efficiently. To deal with these issues, various new construction methods have been developed and applied at building sites to make building operations more efficient and more rational. One of them is the Base Reinforcement System (BRS), which can greatly improve the productivity of building operations through using foundation reinforcement units. At traditional building sites, it is necessary for skilled workers to assemble foundation reinforcement structure by hand, which takes longer working hours. In contrast, when BRS is applied in a building site, foundation reinforcement units are made in the factory in advance and then transported to the building site. As there is fewer operations needed in the site, the foundation reinforcement structure can be completed very efficiently and with high quality. Meanwhile, materials can be shared by multiple building sites, this can lead to reduction of the waste of materials.

Although BRS has many advantages, the prerequisite to get these advantages is efficient production of foundation reinforcement units. In this study, we consider the mixed problem of production scheduling and decision of cutting plan of materials (reinforcement bars) in a foundation reinforcement unit manufacturing factory. In this factory, reinforcement units are manufactured according to customers’ orders with a wide variety of specifications and very short delivery times, it is necessary to decide the best way of cutting materials (reinforcement bars) to reduce waste of materials as low as possible. Meanwhile, manufacturing of reinforcement units needs five processes, some of which can be skipped. There are also limited spaces in storage areas between any two processes to store parts or half-finished units. It is necessary to develop effective production schedules to improve productivity and prevent stagnation between processes.

Deciding the best cutting plan of reinforcement bars is a typical Cutting Stock Problem (CSP), which is to find the best way of cutting large stock materials into smaller ones so as to satisfy the customer demand for these small items. The origin of CSP is in the paper industry, and encountered in a wide variety of industrial applications, such as in the steel, wood and glass industries, and also in service sector applications, such as cargo loading and logistics[1]. Although a great number of solving algorithms of CSP has been reported, these methods cannot be directly used to decide the best cutting plan of reinforcement bars in the considered factory because we have to take the limited spaces in storage areas into account. The CSP with limited cutting pattern is usually denoted as the Bin Packing Problem (BPP) or the Binary Cutting Stock Problem (BCSP) with variable capacity. BPP is also a widely-studied combinatorial optimization problem in the literature. Gupta et. al.[2] proposed a static layout method for high yield of materials called Minimal Bin Slack (MBS) heuristic. Moreover, some improvements on the MBS heuristic have been proposed so as to solve BPP more efficiently [3][10]. In addition to the well-known approximation algorithms with performance guarantees such as first-fit decreasing, best-fit decreasing and worst-fit decreasing, many heuristic algorithms have been developed [5].

Several previous studies have been reported to consider the
mixed problem of scheduling and pre-cutting of materials. Sakaguchi et al. [6] have proposed a hybrid heuristic approach to the scheduling problem of sheet metal processing, which genetic algorithm, dispatching rule and local search technique are applied to create a schedule together with a bottom left algorithm for nesting. Toyoda [7,8] made a revision to first-fit algorithm and proposed a new heuristic solution method for multiple stock length CSP. He has applied the proposed method to a timber pre-cutting problem, and demonstrated that good results were obtained with short calculation times.

This study intends to propose a heuristic solution method for solving the mixed problem of materials’ cutting plan decision and production scheduling for foundation reinforcement unit manufacturing. The emphasis is put on solving a practical problem and making the following contribution:

(1) As previous studies considered the demand from only one customer and decided the best cutting plan of materials, we try to improve the existing researches and consider demands from multiple customers.

(2) In order to provide a practicable solution to the mixed problem of production scheduling and materials’ cutting plan decision, we consider two additional constraints: (A) limited spaces in storage areas between any two processes; (B) batching of similar parts or units.

2. Models Construction

2.1 Manufacturing Process of Reinforcement Units

The manufacturing process of foundation reinforcement units is shown in figure 1, which consists of five processes: cutting, spot welding, bending, welding and combination. All of customers’ orders are usually manufactured through these five processes, but the bending process and welding process can be skipped according to reinforcement units’ specifications.

The storage areas of parts or half-finished units between processes are denoted as buffers in figure 1 and the buffer sizes are used to represent the limited space of storage areas.

According to equipment and manufacturing process of the factory, we can define the production planning problem in the factory as follows:

- Foundation reinforcement units are made by customers’ orders. An order consists of all reinforcement units from one house.
- When conducting production planning, the detailed information of all orders, such as quantity and specifications is known, and materials required to manufacture the orders are available.
- As materials there are enough reinforcement bars with different length and different size (diameter).
- A buffer exists between two processes and its size varies with work days and processes.
- At cutting process, it is necessary to perform a set-up when the size of reinforcement bars changes. At the succeeding processes, set-ups are also necessary according to the specifications of reinforcement units.
- In order to avoid set-ups, we need to batch multiple similar orders or reinforcement units into a lot, and the batching condition at each process varies according to the process’s feature. Furthermore, the lot size should be decided based on both the buffer size behind each process and the machine to process the lot.
- There are more than two machines in each process and a machine can process only one lot at a time.
- A order should be processed within a work day and it cannot be split and processed on two machines at the same time.
- The objective is to decide the best cutting plan of materials and efficient schedules to complete all of customers’ orders.

In order to construct the problem’s models, we define the following notations:

- \( P \) total number of orders
- \( p \) number of an order \((p = 1, 2, ..., P)\)
- \( K \) total number of processes
- \( k \) number of a process \((k = 1, 2, ..., K)\)
- \( M_k \) total number of machines in process \(k\)
- \( m \) number of a machine in the same process \((m = 1, 2, 3, ..., M_k)\)
- \( R_k \) buffer size behind process \(k\) \((k = 1, 2, ..., K - 1)\)
- \( T \) total number of reinforcement bars’ sizes
- \( t \) number of a size of reinforcement bars \((t = 1, 2, 3, ..., T)\)
- \( N_t \) total number of reinforcement bars with size \(t\)
- \( n \) number of a reinforcement bar in the same size \((n = 1, 2, 3, ..., N_t)\)
- \( b_{nt} \) length of reinforcement bar \(n\) in size \(t\)
- \( I_p \) total number of reinforcement units in order \(p\)
- \( j \) number of a part in the same order \((j = 1, 2, 3, ..., J_p)\)
- \( c_{ij}^p \) length of part \(j\) in order \(p\) made of reinforcement bars with size \(t\)
- \( L_k \) total number of lots batched at process \(k\)
- \( l \) number of a lot at the same process \((l = 1, 2, 3, ..., L_k)\)
- \( F_{lm} \) maximum number of parts in one lot batched on machine \(m\) at process \(k\)
- \( s_{lk} \) start time of processing lot \(l\) at process \(k\)
- \( t_{kl} \) operation time required to process lot \(l\) in process \(k\)
- \( ST_{kj}^p \) start time of manufacturing part \(j\) in order \(p\) at process \(k\)
- \( PT_{kj}^p \) operation time required to manufacture part \(j\) in order \(p\) at process \(k\)
- \( MT_{kl} \) setup time required to process lot \(l\) in process \(k\)
- \( Z_{amb} \) 0-1 variable representing processing sequence of lot \(l\) and lot \(m\) on machine \(a\). If lot \(l\) is processed before lot \(m\), \(Z_{amb} = 1\); otherwise \(Z_{amb} = 0\).

We further define the following decision variables:
As the total number of orders is \( P \), and the maximum number of orders which we can consider at a time is \( R_1 \), the total number of group is \( G = \lceil P/R_1 \rceil \), where ceiling function \( \lceil x \rceil \) maps \( x \) to the least integer greater than or equal to \( x \).

According to the above notations and problem’s definition, the model of cutting plan decision can be formulated as:

\[
\max f_{\text{yield}} = \sum_{t=1}^{T} \left( \sum_{p=1}^{P} \sum_{i=1}^{I} c_{ij}^p \right) \sum_{n=1}^{N_i} b_{kn} \tag{1}
\]

subject to:

\[
\sum_{g=1}^{G} x_g^p = 1 \quad (\forall p) \tag{2}
\]

\[
\sum_{p=1}^{P} x_g^p \leq R_1 \quad (\forall g) \tag{3}
\]

\[
\sum_{p=1}^{P} \sum_{j=1}^{J} c_{ij}^p y_{klj}^p \leq b_{kn} \quad (\forall n, \forall l) \tag{4}
\]

In this model, equation (2) shows a constraint that any order must belong to a group; equation (3) is the constraint for the limited number of orders which is able to consider at a time, and equation (4) means that the sum of all parts’ length made of one reinforcement bar in size \( t \) is not greater than the length of the reinforcement bar.

### 2.3 Model of Batching and Scheduling

Batching and scheduling condition is shows in Table 1. In order to reduce set-ups, at cutting process, the parts in a group of orders should be batched into several lots according the sizes of reinforcement bars that the parts are made of. Meanwhile, at the subsequent three processes: spot welding, bending and welding, similar reinforcement units should be batched into one lot with consideration of buffer sizes.

| Process No (k) | Process | Process skipping | Batching by | Buffer size (R_1) |
|---------------|---------|------------------|-------------|-------------------|
| 1             | Cutting | No               | Bar size    | 10 order          |
| 2             | Spot Welding | No       | Units       | 40 units          |
| 3             | Bending | Yes              | Units       | 60 units          |
| 4             | Welding | Yes              | Units       | 20 units          |
| 5             | Combination | No        | Order No.   | -                 |

In order to find efficient schedules to manufacture all orders, we choose minimum makespan as the objective because the minimum makespan means the maximum load over all machines or maximum throughput. From the definition of makespan that is the total time needed to finish all of orders, the objective of scheduling problem can be formulated as:

\[
\min f_{\text{max}} = \max_{p,j} \{ ST_{kj}^p + PT_{kj}^p \} \tag{5}
\]

where \( ST_{kj}^p \) is the start time of manufacturing part \( j \) of order \( p \) at the last process \( K \), and \( PT_{kj}^p \) denotes the operation time required to manufacture part \( j \) of order \( p \) at the last process \( K \). As similar parts are batched into a lot and the processing operations on each machine are conducted in lots, start time \( ST_{kj}^p \) and operation time \( PT_{kj}^p \) of part \( j \) of order \( p \) can be determined according to the start time and operation time of the lot that part \( j \) belongs to. We can given the following formulations:

\[
ST_{kj}^p = \sum_{l=1}^{L} s_{lj}^p y_{klj}^p \quad (\forall p, k, j) \tag{6}
\]
\[ PT_{kj}^p = \sum_{l=1}^{I_i} t_{li} g_{kj}^p + \sum_{m=1}^{M} \sum_{l=1(l \neq l')} Z_{jdk}^{\prime} MT_{lj} \quad (\forall p, k, j) \tag{7} \]

The equation (7) shows that operation time \( PT_{kj}^p \) of part \( j \) of order \( p \) is decided based on set-up time \( MT_{kj} \) and operation time \( t_{li} \) of the lot that part \( j \) belongs to. Decision variable \( g_{kj}^p \) denotes if part \( j \) of order \( p \) is batched into lot \( l \) at process \( k \). \( Z_{jdk}^{\prime} \) shows the processing sequence between lot \( l' \) and lot \( l \) on machine \( m \) in process \( k \), and can be used to calculate set-up times as shown in equation (6).

The following three constraints represent restrictions on processing sequence among parts or lots:

\[ ST_{kj}^{p(l+1)} \geq ST_{kj}^p + PT_{kj}^p \tag{8} \]

\[ z_{ml} - z_{ml'} \geq s_{kl} - s_{kl'} \quad (l \neq l') \tag{9} \]

\[ z_{ml} - z_{ml'} \geq z_{ml} - z_{ml'} - t_{l'} \quad (l \neq l') \tag{10} \]

Where equation (8) is to guarantee start time of parts processing is non-negative; equation (9) and equation (10) represent that a part or a lot cannot be processed simultaneously at two machines or in two processes.

The following equation (11) indicates batching similar parts into a lot at each process; because some processes could be skipped, the left-hand result of this equation is less or equal to 1 (\( \leq 1 \)), instead of being equal to 1 (\( = 1 \)). As decision variable \( z_{ml} \) indicates whether lot \( l \) is processed on machine \( m \) in process \( k \), equation (12) is the constraint to guarantee a lot must be processed on a machine. Meanwhile, equation (13) is used to represent the constraint on buffer size.

\[ \sum_{l=1}^{I_i} g_{kj}^p \leq 1 \quad (\forall p, k, j) \tag{11} \]

\[ \sum_{m=1}^{M} z_{ml} = 1 \quad (\forall k, l) \tag{12} \]

\[ \sum_{p=1}^{P} \sum_{j=1}^{J_p} g_{kj}^p z_{ml} = 1 \leq F_{km} \quad (\forall k, m, l) \tag{13} \]

Furthermore, we introduce a 0-1 variable to represent the relation between parts and reinforcement units:

\[ d_{ij}^p = \begin{cases} 1: \text{if part } j \text{ belongs to unit } i \text{ of order } p \\ 0: \text{otherwise} \end{cases} \]

The following equation (14) and equation (15) can guarantee that all of parts and reinforcement units are made without redundancy.

\[ \sum_{i=1}^{I_i} d_{ij}^p = 1 \quad (\forall p, j) \tag{14} \]

\[ \sum_{p=1}^{P} \sum_{i=1}^{I_i} \sum_{j=1}^{J_p} d_{ijn}^p = 1 \quad (\forall j) \tag{15} \]

3. Solution Method

3.1 Overview of Solution Method

Figure 2 shows the flow chart of our solution method. After the data of all customers’ orders are ready, we conduct cutting decision to decide the orders’ grouping and their cutting pattern of reinforcement bars to increase the yield of materials as high as possible, considering the buffer size behind cutting process. Then, batching and initial scheduling is to be conducted to batch similar parts or units into a lot for each process intending to reduce set-ups, and construct an initial schedule. Next, the SA-based local searching is performed to improve the initial schedule and find the best schedule for all of orders.

![Flow chart of solution method](image)

3.2 Solution Method of Cutting Plan Decision

Applying the Revised Minimal Bin Slack (RMBS) heuristic, that was proposed by Toyoda [7], we propose the following solution method to decide the best cutting plan for customers’ orders:

[Step 1] Let \( TR \) denote the list of all orders, \( RES \) be the list of orders with their parts’ cutting plan. And \( R \) is the maximum number of orders for one group.

[Step 2] For all orders in \( TR \), generate all combinations of \( R \) orders. Each combination of \( R \) orders is regarded as one group and the list of all of these groups is denoted as \( Q = \{ Q(c); c = 1, 2, 3, \ldots \} \). For each group \( Q(c)(c = 1, 2, 3, \ldots) \), perform the following step 2.1 to step 2.2 and then go to step 3.

[Step 2.1] Take one group \( Q(c) \) from \( Q \), and list all the parts that need to be made for the orders in \( Q(c) \) in order of decreasing length.

[Step 2.2] Applying RMBS heuristic to decide the cutting plan \( CP(c) \) for the orders in \( Q(c) \) and calculate the yield rate of \( CP(c) \).

[Step 3] For all of cutting plan \( CP(c)(c = 1, 2, 3, \ldots) \), find the best one \( CP(C) \) which corresponds to the maximum of yield rates and denote the corresponding order group as \( Q(C) \). Add \( CP(C) \) and \( Q(C) \) to \( RES \). Then, remove all orders in \( Q(C) \) from \( TR \).
[Step 4] If there is any order in TR, go back to step 2. Otherwise, go to step 5.

[Step 5] Stop. RES is the best cutting plan.

3.3 Batching and Constructing Initial Schedule
As described above, similar parts or units of all orders should be batching into a lot. Figure 3 shows an example of orders batching, where there are two orders and these two orders could be batched by the bar type (the size of reinforcement bars that the parts are made of) as shown in the top right of figure 3; meanwhile they could also be batched according to the similarity among units as shown in the bottom right of figure 3. Because batching condition and lot size depend on the process, it is difficult to decide orders batching and their manufacturing schedule simultaneously. We propose the following heuristic method to solve this problem:

1. At first, apply the solution method described in previous section to decide the best cutting plan and obtain the orders grouping to reduce waste of materials. The batching and scheduling are conducted based on these groups of orders.

2. Calculate the total operation times required to process all group of orders for each process, and then find the longest operation time and define the corresponding process as the bottleneck process bp. If there are more than two bottleneck processes, choose the process that cannot be skipped or more previous process.

3. At the bottleneck process bp, batch the parts or units for each group of orders based on the criterion of minimum set-ups. Then, according to the FIFO (First In First Out) rule, decide the start time for every lot at the bottleneck process bp. That is, determine the start time for every lot in the increasing sequence of lot number.

4. At process k (k = bp + 1, bp + 2, ..., K), batch similar units and decide the start time of every lot according to the FIFO rule.

5. At process k (k = bp − 1, bp − 2, ..., 1), batch similar units into a lot, and consider the start time at process k + 1 as the due time at process k. Furthermore, decide the start time of every lot at process k according to the EDD (Earliest Due Date) rule.

Figure 4 shows an example of constructing initial schedule.

3.4 Finding the Best Solution Through Local Searching
After the initial schedule was constructed, we apply Simulated Annealing (SA) based local search to find the best solution. The flow of local searching is shown in figure 5. The candidate solution is generated through the following two neighbors.

1. neighbor N1: Interchange the processing sequence of two parts or units that were randomly selected in a lot.

2. neighbor N2: Interchange the processing sequence of two parts or units that were randomly selected in two different lots.

As neighbor N2 results in a change in batch of parts or units, better solution can be reached with higher possibility.

### 4. Computer Experiments

#### 4.1 Experiment Setting
To demonstrate the effectiveness of the proposed solution method, we apply it to a practical problem with 11 orders. The number of parts by the bar size and units is shown in table 2. There are three sizes: 10mm, 13mm and 16mm and five lengths: 4000mm, 4500mm, 5000mm, 5500mm and 6000mm of reinforcement bars. The length of parts ranges from 1090mm to 4800mm; the total number of parts in each order is up to 370.

| Order No. | Bar size | Number of units |
|-----------|-----------|------------------|
| 1         | 10mm      | 26               |
| 2         | 10mm      | 116              |
| 3         | 13mm      | 150              |
| 4         | 13mm      | 29               |
| 5         | 16mm      | 17               |
| 6         | 16mm      | 3                |
| 7         | 16mm      | 10               |
| 8         | 10mm      | 3                |
| 9         | 10mm      | 30               |
| 10        | 10mm      | 12               |
| 11        | 10mm      | 2                |

Table 3 shows the operation and set-up time for each lot at every process. The operation time varies with the parts’ number in a lot, and it is (5-10 minutes) × number of parts or units. A set-up occurs in every lot and it takes five to 10 minute. Table 4 shows the parameters and their setting values for SA-based local searching. Starting from the initial schedule described in section 3.3 and setting the initial temperature as $T_{SA}$=100, at first we generate a neighbor N1 as a candidate schedule and decide whether to replace the current schedule.
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4.2 Experiment Results

4.2.1 The Best Yield and Buffer Size

To demonstrate how the buffer size behind the cutting process impacts yield of materials, we set the buffer size behind cutting process as \( R_i = 1, 2, 3, ..., 11 \) respectively and calculated the best yield rate of materials through the method proposed in section 3.2. The result is shown in table 5 and figure 6. The computing time required to decide the best cutting plan is the executing time of our method at a personal computer with Intel(R) Core(TM) i7-7700HQ 2.8GHz CPU and 16GB RAM.

| Buffer size | Best yield by bar type | Computing time (min) |
|-------------|------------------------|----------------------|
| 10mm        | 93.92%                 | 98.87%               | 96.65%               | 3       |
| 13mm        | 94.74%                 | 98.88%               | 98.29%               | 32      |
| 16mm        | 94.91%                 | 98.88%               | 98.86%               | 32      |
| 20mm        | 95.30%                 | 98.88%               | 98.74%               | 360     |
| 25mm        | 95.32%                 | 98.88%               | 98.96%               | 400     |
| 30mm        | 95.18%                 | 98.88%               | 96.46%               | 245     |
| 35mm        | 95.39%                 | 98.88%               | 97.40%               | 30      |
| 40mm        | 95.62%                 | 98.88%               | 98.57%               | 22      |
| 45mm        | 95.76%                 | 98.88%               | 99.03%               | 9       |
| 50mm        | 96.59%                 | 98.88%               | 99.11%               | 2       |
| 55mm        | 96.59%                 | 98.88%               | 99.11%               | 25      |

From table 5 and figure 6, it is clear that:

The results in table 5 and figure 6 show that the buffer size significantly impacts the yield of materials. As the buffer size increases, the yield rate also increases. The computing time required to decide the best cutting plan is the executing time of our method at a personal computer with Intel(R) Core(TM) i7-7700HQ 2.8GHz CPU and 16GB RAM.
To clarify the executed 10 times, Table 6 shows the basic statistics of makespan.

4.2.2 Result of Scheduling

(1) Lower yield rates appeared when $R_1 = 1$. Notice that this result is identical to the method proposed by Toyoda [7]. It is obvious that the yield rate of materials could be improved if we consider multiple orders simultaneously and decide the best cutting plan of materials.

(2) For the reinforcement bar of 10mm in size, the yield rate increases in proportion to increase in buffer size. Meanwhile, there is almost no change in the yield rate for the reinforcement bar of 13mm. Moreover, the lowest yield rate of the reinforcement bar of 16mm appeared when $R_1 = 6$. That is, increasing buffer size does not necessarily lead to higher yield rate of materials.

(3) When $R_1 = 4,5$, the computing time were 360 and 400 minute (not less than 6 hours). There is a reasonable buffer size that enable the proposed method to obtain the best cutting plan in an acceptable time.

(4) Overall, when $R_1 = 10$, we could obtain the highest yield rate in the shortest computing time.

4.2.2 Result of Scheduling

Setting $R_1 = 10$ and conducting the heuristic method proposed above to construct the best schedule, we obtained the scheduling result shown in table 6. As the heuristic method was executed 10 times, Table 6 shows the basic statistics of makespan. To clarify the effectiveness of our method, we also set $R_1 = 1$, that is, applying the RMBS method proposed by Toyoda [7] to decide the best cutting plan and then constructed production schedule, the result is shown in table 6 as "RMBS based method".

| Statistics        | Proposed method | RMBS based method |
|-------------------|-----------------|-------------------|
| Average           | 96796.43        | 101336.17         |
| Maximum           | 98985           | 105315            |
| Minimum           | 94817           | 96901             |
| Standard deviation| 1733            | 3665              |

From table 6, it is clear that:

(1) The average of makespan obtained through RMBS based method is 101336.17, the proposed method could reduce it by 4.5% to 96796.43.

(2) The standard deviation of makespan obtained through RMBS based method is 3665, the proposed method could reduce it by 52.7% to 1733. That is, the proposed method can stably obtain the best schedule with less standard deviation.

(3) The result suggests that if we consider multiple orders simultaneously, better production schedules can be obtained with shorter makespan and less variation.

Figure 7 shows how makespan decreases with the iterations of SA-based searching. When applying the proposed method, the makespan of the initial schedule was 99732, and it deceased to 94817 through 5000 iterations of local searching. In more detail, the makespan was reduced only four times in 5000 iterations. As most of reduction in makespan occurred after the temperature $T_{SA}$ drops below 50, this suggests that generating a neighbor $N1$ as a candidate schedule is less effective to improve the makespan. Meanwhile, although generating a neighbor $N2$ enabled to provide candidate solution to reduce makespan, the proportion of effective solutions is very low.

5. Conclusion

In this study we considered the practical production planning problem in a foundation reinforcement unit Manufacturing factory, and proposed a heuristic solution method to solve the mixed problem of materials’ cutting plan decision and production scheduling. The main results obtained can be summarized as follows:

(1) When deciding the best cutting plan of materials, the yield rate of materials could be improved through considering multiple orders simultaneously instead of considering one order at a time. However, it required longer computing time to obtain the best cutting plan and therefore it is necessary to find a reasonable number of orders to consider simultaneously in an acceptable time.

(2) Through considering multiple orders simultaneously, we can also obtain better production schedule with shorter makespan and less variation.

(3) The SA-based local searching proposed above could improve makespan, but the effectiveness depends largely on how to generate effective candidate solutions.

Further researches are necessary to improve the solution method of cutting plan decision to shorten computing time, propose more effective methods to generate candidate schedule to reduce makespan.

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