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聚氯乙烯膠皮工廠中總延遲時間最小化之排程問題

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中文摘要：

本計畫研究一個實務的等效平行機生產排程問題，此排程問題是由一座生產聚氯乙烯膠皮產品的工廠中衍生而來。在這個實務的生產排程問題中，每一件聚氯乙烯膠皮產品具有某些特定的屬性，且每個屬性具有一些不同的規格。由於在機器上任兩個相鄰的聚氯乙烯膠皮產品之間，至少會有一個屬性具有不同的規格，因此當某個聚氯乙烯膠皮產品完成生產而切換到生產另一種產品時，在機器上必須調整規格而導致整備時間的發生。由於延遲時間在聚氯乙烯膠皮產品的生產上會導致額外的懲罰成本與機會損失，因此，在這個個案工廠中的排程經理將總延遲時間最小化視為最重要的任務之一。這個問題可歸類為具有多重屬性整備時間之等效平行機生產排程問題，目標是總延遲時間最小化。本計畫會發展一個派工法則來求解此問題，並且會與個案工廠現有的排程方法以及一個現有知名的派工法則作比較。此外，也會提出一個混合整數規畫模型來評估本計畫所提出之方法的效果。最後，將會進行一個統計分析以便驗證本計畫所提出之方法的整體績效。

中文關鍵詞：排程；總延遲時間；等效平行機；多重屬性整備時間；派工法則

英文摘要：

This proposal addresses a real-life production scheduling problem with identical parallel machines, originating from a manufacturing plant producing polyvinyl chloride (PVC) leather products. In the considered practical production scheduling problem, PVC leather has some specific attributes and each attribute has several different levels. As there is at least one different level of attribute between two PVC leather products, it is necessary to make a setup adjustment on each machine whenever a switch occurs from processing one PVC leather product to a different type of PVC leather product. As tardiness in the production of PVC leather products leads to extra penalty costs and opportunity losses, the objective of minimizing total tardiness has become one of the most important tasks for the schedule manager in the case study plant. The problem can be classified as a production scheduling problem to minimize the total tardiness on identical parallel machines with multi-attribute setup times. A dispatching rule will be developed for this problem and evaluated by comparing it with the current scheduling method in the case plant and a current dispatching rule. Moreover, a mixed integer programming model will be used to evaluate the effectiveness of the proposed constructive heuristic. Finally, a statistical analysis will be conducted to verify the performance of the proposed constructive heuristic.

英文關鍵詞： Scheduling； Total tardiness； Identical parallel machines； Multi-attribute setup times； Dispatching rule

Scheduling problem for minimizing total tardiness in a polyvinyl chloride leather plant

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Abstract

This paper addresses a real-life production scheduling problem with identical parallel machines, originating from a manufacturing plant producing polyvinyl chloride (PVC) leather products. In the considered practical production scheduling problem, PVC leather has some specific attributes and each attribute has several different levels. As there is at least one different level of attribute between two PVC leather products, it is necessary to make a setup adjustment on each machine whenever a switch occurs from processing one PVC leather product to a different type of PVC leather product. As tardiness in the production of PVC leather products leads to extra penalty costs and opportunity losses, the objective of minimizing total tardiness has become one of the most important tasks for the schedule manager in the case study plant. The problem can be classified as a production scheduling problem to minimize the total tardiness on identical parallel machines with multi-attribute setup times. A dispatching rule is developed for this problem and evaluated by comparing it with the current scheduling method and the apparent tardiness cost with setups (ATCS) dispatching rule. Moreover, a mixed integer programming model is used to evaluate the effectiveness of the proposed constructive heuristic. Based on a statistical analysis, the proposed constructive heuristic outperforms the ATCS with a significant improvement.

Keywords: Scheduling; Total tardiness; Identical parallel machines; Multi-attribute setup times; Dispatching rule

1. Introduction

In this research we address a real-life scheduling problem related to the production of Polyvinyl Chloride leather (hereafter referred to as PVC leather), a typical continuous process industry. PVC leather is a thermoplastic material used for shoes, furniture, interiors for boats and vehicles, bikes, and accessories for baggage, etc. PVC leather production is a highly capital intensive industry, which includes a main machine, called a leather calender, and some peripheral equipment. To maximize the utilization of the equipment, the plant runs three shifts; eight hours per shift, and seven days a week. The capacity of the PVC leather production system is determined by the leather calendar, which becomes the bottleneck in such a system.

A PVC leather plant receives purchase orders from different clients. Each purchase order contains the number of required PVC leather products, each of which has five attributes: marking, hardness, width, color, and thickness. Each attribute has several levels and has a corresponding attribute setup time. A PVC leather product of a particular purchase order can be regarded as a job on the scheduling operation. Those PVC leather products that all have the same levels of the five attributes are always grouped into a single job, such that no additional setup time is incurred. Because there is at least one different level of attribute between two sequential jobs, it is necessary to make a setup adjustment whenever there is a switch from processing one job to another on the leather calender. For example, if the levels of marking and width are different between two sequential jobs, there is the need to adjust the levels of marking and width on the leather calender. This results in a setup time equal to the sum of the attribute setup times of marking and width. Therefore, the setup time between two sequential jobs is determined by adding up those attribute setup times of the different levels of attributes. The processing time of each PVC leather product normally takes three to fifteen hours. Each product has a due date specified by the client, and must be delivered to the client before its due date.

There are four leather calenders in the plant under consideration, in general, each producing a different PVC leather product. However, clients always place many purchase orders for those PVC leather products with common specifications in peak season and thus, the production lines of the products are usually overloaded. Therefore, the schedule manager in the plant has to allocate some other leather calenders to share the load of an overloaded leather calender, which then creates an identical parallel machine environment. The clients always pay more attention to the due dates that they have requested during peak season. Tardiness will be incurred when the completion time of a job is later than its due date. With respect to the tardiness incurred, the sales representative in the plant has to spend additional time negotiating with the client in order to postpone the due date of the job. Generally, the client might accept a slight change to the due date, but if the completion time of a job exceeds its due date by too long, a penalty cost associated with the tardiness is usually incurred. The usual situation is that the client accepts the delay of delivery time, but asks to get a discount on the unit price of the tardy job, or cuts the payment directly. The worst situation is that the client cancels the purchase order and turns to other competitors who can meet the requested due date. These situations lead to a significant loss of revenue for the PVC leather plant. The schedule manager in the plant has to have strict control over tardiness in order to reduce extra penalty costs and opportunity losses. Therefore, the objective of minimizing total tardiness has become one of the most important tasks for the schedule manager in the plant. Our interest in this research focuses on the tardiness of the identical parallel machine environment. This problem can be classified as an identical parallel machine scheduling problem with multi-attribute setup times for minimizing total tardiness.

In this paper, we develop an effective dispatching rule to fit the requirements of the PVC leather plant. To evaluate its performance, the proposed dispatching rule will be compared with the current scheduling method of the plant and an existing scheduling approach. Moreover, a mixed integer programming (MIP) model is used to evaluate the effectiveness of the proposed dispatching rule.

2. Literature review

Related works in the literature are briefly reviewed in this section. Many authors have much effort in solving parallel machine scheduling problems with sequence-dependent setup times for minimizing the due date related objectives. A complete review can be found in Allahverdi et al. (2008). Radhakrishnan and Ventura (2000) addressed a parallel machine earliness-tardiness non-common due date sequence-dependent setup time scheduling problem. The objective was to minimize the sum of the absolute deviations of job completion times from their corresponding due dates, i.e., $\sum E_i + \sum T_i$. They presented a mathematical programming formulation that can be used for solving limited-sized problems to optimality, and proposed a simulated annealing algorithm for large-sized problems to improve further the solutions obtained by a local search heuristic. Feng and Lau (2005) addressed the more general problem, i.e., $\sum w_i E_i + \sum w_i T_i$, and proposed a meta-heuristic, called squeaky wheel optimization, to solve the presented problem. Computational results showed that their meta-heuristic outperforms that of Radhakrishnan and Ventura (2000). Kim and Shin (2003) presented a restricted tabu search algorithm on either identical or non-identical parallel machines in order to minimize the maximum lateness $(L_{\max})$ of the jobs. The jobs had release times and due dates, and sequence-dependent setup times existed between the jobs. The experimental results showed that the proposed algorithm obtained much better solutions more quickly than other heuristic algorithms, such as the basic tabu search and simulated annealing. For problems with the total (weighted) tardiness objectives ($\sum T_i$ or $\sum w_i T_i$), Bilge et al. (2004) presented a tabu search algorithm for the total tardiness problem. They investigated several key components of tabu search and identified the best values for these components. They compared their meta-heuristic with the genetic algorithm of Sivrikaya-Serifoglu and Ulusoy (1999) for the case of zero weight for earliness, and the computational results showed that their meta-heuristic outperforms the genetic algorithm. Tavakkoli-Moghaddam et al. (2009) addressed a parallel machine problem to minimize bi-objectives, namely the number of tardy jobs ($\sum U_i$) and the total completion time ($\sum C_i$). They presented a two-level mixed integer programming model and an efficient genetic algorithm (GA) to solve the bi-objective scheduling problem. The performance of the presented model and the proposed GA was verified by a number of numerical experiments. The related results showed the effectiveness of the proposed model and GA for small- and large-sized problems.

There is some research in the scheduling literature that discusses industrial applications of parallel machine for minimizing due date related objectives. Chen (2006) proposed a scheduling problem on unrelated parallel machines with process restrictions and setups to minimize maximum tardiness ($T_{\max}$) in a die-casting environment. A setup for dies was incurred if the type of job scheduled was different from the previous one on that particular machine. An efficient heuristic based on guided search, record-to-record travel, and tabu lists was presented for the problem. Kim et al. (2002) presented a parallel machine scheduling problem with sequence-dependent setup times in compound semiconductor manufacturing. A simulated annealing (SA) meta-heuristic was employed in the research to determine a scheduling policy in order to minimize total tardiness ($\sum T_i$). Chen and Wu (2006) dealt with a scheduling problem on unrelated parallel machines with auxiliary equipment constraints. Such a production environment could be found in the die-casting and injection-molding industries. A setup for dies was incurred if there was a switch from processing one type of job to another. An effective heuristic based on threshold-accepting methods, tabu lists, and improvement procedures was proposed to minimize total tardiness ($\sum T_i$). Computational experiences demonstrated that the proposed heuristic was capable of obtaining optimal solutions for small-sized problems, and significantly outperformed an existing algorithm and a simulated annealing method for problems of larger sizes.

Many studies have applied or modified the apparent tardiness cost (ATC) dispatching rule for total weighted tardiness scheduling problems on parallel machines ($Pm//\sum w_i T_i$). The ATC was developed earlier by Vepsalainen and

Morton (1987). For the same problems with setup considerations $(Pm / s_{ij} / \sum w_i T_i)$, Lee and Pinedo (1997) built upon the ATC and developed a three-phase approach consisting of identifying problem instance characteristics, finding an initial schedule using the apparent tardiness cost with setups (ATCS) rule, followed by simulated annealing to improve the solution. Eom et al. (2002) presented a three-phase heuristic to minimize total weighted tardiness. In the heuristic, jobs were listed by earliest due date, grouping jobs by ATCS, and sequencing jobs according to setup types improved by tabu search and allocating jobs to machines. Park et al. (2000) proposed an extension of the ATCS rule that utilized some look-ahead parameters for the calculation the priority index of each job for the total weighted tardiness problem. Their computational results showed that their proposed algorithm was better than an earlier approach. Based on the ATCS rule, Pfund et al. (2008) developed an apparent tardiness cost with setups and ready times (ATCSR) index to be used in their proposed approach. Their experiments indicated that the ATCSR-based approach provided better performance than some other algorithms that were extended from ATCS.

3. Problem formulation

Without loss of generality, in the following, we will use “job” and “machine” to represent the PVC leather product and the leather calender, respectively. The following notations will be used throughout this paper:

m	number of machines
M_k	machine k, $k = 1, \ldots, m$
n	number of jobs
J_i	job i, $i = 1, \ldots, n$
p_i	processing time of J_i, $i = 1, \ldots, n$
C_i	completion time of J_i, $i = 1, \ldots, n$
w_i	weight of J_i, $i = 1, \ldots, n$

d_i	due date of J_i, $i=1,...,n$
T_i	tardiness of J_i, $i=1,...,n$
A_a	attribute a, $a=1,...,5$ (A_1 to A_5 stands for marking, hardness, width, color and thickness, respectively)
NL_a	number of different levels of A_a throughout the job set, $a=1,...,5$
$N_a(J_i)$	number of jobs with the same level of attribute a as J_i, $a=1,...,5$
s_{ij}	sequence-dependent setup time whenever J_i is processed immediately after J_i, $i,j=1,...,n, i\neq j$
S_a	the $a\,th$ attribute setup time, $a=1,...,5$

The scheduling problem addressed in this paper consists of n jobs processed on m identical parallel machines. Each J_i $(i=1,...,n)$ has a specified processing time p_i and due date d_i, and can be processed on each machine arbitrarily. A setup time must occur between any two sequential jobs. All machines are available to process jobs at time zero, at which time all jobs are ready to be processed. No interruptions and pre-emptions in the processing of a job are allowed, and there is no priority for any jobs. The machine can process at most one job at a time, and no job can be processed on more than one machine simultaneously. The objective is to find a schedule that minimizes the total tardiness of all jobs. The tardiness is one of the important performance measures for a production system, especially during the peak season. Another reason for choosing total tardiness as the criterion to be minimized is that it is less likely that the wait of any given job will be unacceptably long (Pinedo, 2002). The tardiness of J_i is defined as $T_i=\max\{C_i-d_i,0\}$. Moreover, there is no priority among the jobs in the case plant (i.e., $w_i=1$, $i=1,...,n$); therefore, the objective is as follows:

$$\text{Minimize } \sum_{i=1}^{n} T_i \tag{1}$$

Following the three-field notation, the problem can be denoted by $Pm/s_{ij}/\sum T_i$, where Pm designates m identical parallel machines, s_{ij} represents the sequence-dependent setup time, and $\sum T_i$ denotes the total tardiness for all jobs. A sequence-dependent setup time $s_{ij} > 0$ is incurred whenever a machine switches the production from J_i to J_j. Because a schedule is computed for a given horizon, no setup time is necessary before the job scheduled at the beginning of the schedule.

Du and Leung (1990) prove that minimizing the sum of the tardiness on a single machine (i.e., $1//\sum T_i$) is NP-hard. Hence, $1/s_{ij}/\sum T_i$ is also NP-hard, because the sequence-dependent setup times between the jobs further complicates the problem. Moreover, the single machine problem reduces to the parallel machine problem, such that the considered problem $Pm/s_{ij}/\sum T_i$, is also NP-hard. According to the related literature review, although there has been some research that has dealt with parallel machine problems with sequence-dependent setup times for minimizing total tardiness, no previous work has addressed directly the total tardiness scheduling problem with multi-attribute setup times in a parallel machine environment. Because the schedule manager in the plant can easily pay more attention to the attributes with longer attribute setup times, it is advantageous to preserve the characteristic of multi-attribute setup times in the scheduling. Because the schedule manager does not want to lose the characteristic of multi-attribute, from the viewpoint of practical applications, we need to develop an effective method that can directly solve the total tardiness problem with the characteristic of multi-attribute setup times.

In general, an optimal way to solve the $Pm/s_{ij}/\sum T_i$ problem is to formulate it into a mathematical program and solve it for small-sized problems by commercial optimization software (such as ILOG CPLEX). In the following, we present a mixed integer programming (MIP) model for the scheduling problem, based in part on the formulation given by Balakrishnan et al. (1999) for the uniform parallel machine case. The decision variables are introduced as follows, and L, a very large number, will be used in the MIP model.

$$y_{ik} = \begin{cases} 1 & \text{job } i \text{ is processed on machine } k \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ij} = \begin{cases} 1 & \text{job } i \text{ precedes job } j \text{ on the same machine} \\ 0 & \text{otherwise} \end{cases}$$

The problem $Pm / s_{ij} / \sum T_i$ can be formulated as follows:

$$\text{Minimize } \sum_{i=1}^{n} T_i \tag{2}$$

subject to

$$\sum_{k=1}^{m} y_{ik} = 1, \qquad i = 1,\ldots,n \tag{3}$$

$$y_{ik} + \sum_{k' \neq k} y_{jk'} + x_{ij} \leq 2, \qquad i = 1,\ldots,n-1; \quad j = i+1,\ldots,n; \quad k = 1,\ldots,m \tag{4}$$

$$C_j - C_i + L(3 - x_{ij} - y_{ik} - y_{jk}) \geq p_j + s_{ij}, \qquad i = 1,\ldots,n-1; \quad j = i+1,\ldots,n; \quad k = 1,\ldots,m \tag{5}$$

$$C_i - C_j + L(2 + x_{ij} - y_{ik} - y_{jk}) \geq p_i + s_{ji}, \qquad i = 1,\ldots,n-1; \quad j = i+1,\ldots,n; \quad k = 1,\ldots,m \tag{6}$$

$$C_i \geq p_i y_{ik}, \qquad i = 1,\ldots,n; \quad k = 1,\ldots,m \tag{7}$$

$$T_i \geq C_i - d_i, \qquad i = 1,\ldots,n \tag{8}$$

$$T_i \geq 0, \qquad i = 1,\ldots,n \tag{9}$$

The objective (2) is to minimize the total tardiness of the problem. Constraint (3) ensures that each job is scheduled exactly on one machine. Constraint (4) ensures that the job precedence between jobs i and j is relevant only if both jobs are assigned to the same machine, i.e., where x_{ij} might equal zero (implying job j before job i) or one (implying job i before job j) if both jobs i and j are assigned to the same machine. x_{ij} must equal zero if these jobs are assigned to different machines. Constraints (5) and (6) establish the relationship between the completion times of jobs i and j as long as both jobs are assigned to the same machine. Constraint (7) is relevant only if y_{ij} equals one (i.e., job i is processed on machine k) and it determines their completion times. If $y_{ij} = 0$, constraint (7) becomes redundant. Finally, constraints (7) and (9) determine the objective value.

Solving the MIP is one of the best ways for small-sized problems, but the larger-sized problems are difficult to solve practically by common commercial software such as CPLEX. Therefore, it is necessary to propose an efficient constructive heuristic for solving large-size problems.

4. Current scheduling method

The addressed scheduling problem with multi-attribute setup times in PVC leather production involves processing jobs on identical parallel leather calenders to minimize the total tardiness. The standard attribute setup times proclaimed by the case study PVC leather plant are shown in Table 1.

[Insert Table 1 here.]

For the scheduling manager of the case plant, there are two main considerations in dealing with the proposed parallel machine problem during peak season. The first is to determine those jobs to be assigned to which leather calender for balancing of the loads. The second is to re-sequence the jobs in order to reduce the tardiness of the jobs on each of the leather calenders. Based on those considerations, here we introduce the scheduling method currently employed in the PVC leather plant:

Step 1 Choose J_i with the longest processing times and assign J_i to the leather calenders just freed. Repeat the step until all jobs are assigned.

Step 2 For each of the leather calenders, re-sequence the jobs in increasing order of due dates.

Now we briefly explain the current scheduling method of the plant. In Step 1, the schedule manager uses the longest processing time first (LPT) rule to assign the m longest jobs to the m leather calenders, respectively. After that, whenever a leather calender is available, the longest job among those not yet processed is assigned on the leather calender. The LPT rule tries to place the shorter jobs towards the end of the schedule where they can be used for balancing the loads. In a Pm environment, it makes sense to use the LPT rule to obtain a good solution without due date and setup time considerations. Then, the earliest due date first (EDD) rule is applied to re-sequence the jobs for reducing the tardiness on each of the machines in Step 2.

Example 1

A real-life case from the considered PVC leather plant with 10 jobs is given in Table 2. We use this real case to explain the current scheduling method.

[Insert Table 2 here.]

In Step 1, a schedule $M_1 = (J_8, J_3, J_9, J_{10}, J_6)$, $M_2 = (J_5, J_7, J_1, J_4, J_2)$ is obtained by using the LPT rule in terms of p_i. In Step 2, the EDD rule is applied to re-sequence the jobs on each machine and leads to the final schedule $M_1 = (J_{10}, J_3, J_8, J_9, J_6)$ and $M_2 = (J_5, J_2, J_7, J_1, J_4)$ with $\sum T = 447$ minutes. We can solve the case problem by the MIP model and the optimal schedule is $M_1 = (J_9, J_7, J_5, J_1)$ and $M_2 = (J_8, J_3, J_{10}, J_2, J_6, J_4)$ with $\sum T = 52$ minutes. The corresponding Gantt charts of the both schedules are shown in Fig. 1 and Fig. 2, respectively. Hence, developing an efficient algorithm to improve the schedule further is very important in the considered PVC leather plant. In the following section, an algorithm is represented to improve the current method.

5. Dispatching rule

In this section, we will propose a dispatching rule for the considered parallel machine scheduling problem with multi-attribute setup times. The objective is to determine a schedule for parallel machines to minimize the total tardiness. The dispatching rule combines an index developed by Lee et al. (2012) and the ATCS by Lee and Pinedo (1997).

5.1. Adjacent processing time and due date index

Three critical considerations are relevant for minimizing the total tardiness in parallel machine scheduling problems with sequence-dependent setup times. They are balancing the loads on machines, reducing the setup times, and the total tardiness for each machine. For the purpose of balancing the loads and reducing the setup times and total tardiness, we introduce an index for the development of a heuristic. The index, called the adjacent processing time and due date index (APD_i), comprises the least flexibility index first principle (Liao et al., 2009), processing times, and due dates. The index is calculated as follows:

$$APD_i = \frac{\ln\left\{\sum_{a=1}^{5}[S_a \times N_a(J_i) \times d_i]\right\}}{p_i} \tag{10}$$

where p_i is the processing time of J_i, S_a denotes the a-*th* attribute setup time, and $N_a(J_i)$ stands for the number of jobs with the same level of attribute a as J_i. Following the real case in Table 2, for example, to compute the value of APD_1, there are: three jobs with the same level of marking (i.e., 270), one job with the same level of width (i.e., 30), two jobs with the same level of thickness (i.e., 0.8), three jobs with the same level of hardness (i.e., 7), and four jobs with the same level of color (i.e., 1). Therefore, APD_1 is computed as:

$$APD_1 = \frac{\ln[(60\times 3+15\times 1+20\times 2+15\times 3+10\times 4)\times 2315]}{444} = 0.030$$

The adjacent processing time and due date index considers processing times, job flexibility, setup times, and due dates simultaneously. In a parallel machines environment, the consideration of balancing the loads is quite important for assigning jobs on machines. For balancing the loads on parallel machines, the longest processing time (LPT) first rule always yields a reasonable solution. To emphasize the characteristic of the LPT rule, we use processing time directly in the index without modification. Then, for minimizing the total tardiness, the earliest due date (EDD) first rule is also involved in the index equation formula. Based on the characteristics of the LPT rule, the least flexibility first principle, and the EDD rule, a job with large processing time or small adjacent index and due date should be sequenced towards the beginning of the schedule. Therefore, if a job possesses a small adjacent processing time and due date index, it should be sequenced towards the beginning of the schedule.

5.2. Apparent tardiness cost with setups (ATCS) index

As the proposed constructive heuristic is based on the apparent tardiness cost with setups (ATCS) dispatching rule given by Lee and Pinedo (1997), a brief introduction of the ATCS will be described first. The ATCS rule is a very famous dispatching rule and is used extensively in production scheduling problems to minimize the total tardiness. The basic idea of the rule is to calculate the ATCS for each of the unprocessed jobs ready whenever a machine becomes available. Then, the job with the highest ATCS index is chosen to be assigned next on the freed machine. The ATCS combines the weighted shortest processing time (WSPT) first rule, the minimum slack (MS) first rule, and the shortest setup time (SST) first rule in a single ranking index. The index of J_i at time t when J_i has completed its processing on the machine is determined by multiplying the corresponding terms as:

$$I_i\left(t,j\right)=\frac{w_i}{p_i}\exp\left(-\frac{\max\left(d_i-p_i-t,0\right)}{K_1\bar{p}}\right)\exp\left(-\frac{s_{ji}}{K_2\bar{s}}\right) \tag{11}$$

where $\bar{s}$ and $\bar{p}$ are the average of the setup times and the average of the processing times, respectively. K_1 and K_2 are two important parameters for determining this dispatching rule. In this paper, the values of both parameters for the considered problem are estimated according to the function developed by Lee and Pinedo (1997). The function used for the selection of proper values for K_1 and K_2 is computed as:

$$K_1=1.2\ln(\frac{n}{m})-R, \qquad \begin{cases} K_1=K_1-0.5 & \tau<0.5 \\ K_1=K_1-0.5 & \eta<0.5, \mu>5 \end{cases} \tag{12}$$

$$K_2 = \frac{\tau}{A_2\sqrt{\overline{s}/\overline{p}}}, \qquad \begin{cases} A_2 = 1.8 & \tau < 0.8 \\ A_2 = 2.0 & \tau \geq 0.8 \end{cases} \tag{13}$$

where τ and R are the factors associated with the due date. τ is the due date tightness factor and R is the due date range factor.

Example 2

Referring to the data in the case plant (see Table 2), the ATCS dispatching rule leads to the final schedule $M_1 = (J_{10}, J_3, J_9, J_6, J_1)$ and $M_2 = (J_3, J_2, J_7, J_5, J_4)$ with $\sum T = 115$ minutes. The corresponding Gantt charts of both schedules are shown in Fig. 3. It is obvious that the ATCS generates a better schedule. However, it is possible to improve the schedule further by involving the adjacent processing time and due date index in the ATCS, as the optimal solution is 52. The remainder of this section describes the ATCS involving the adjacent processing time and due date index.

5.3 ATCS with the adjacent processing time and due date (ATCS_APD) index

The ATCS_APD index is given by:

$$I_{ATCS\_APDi}(t, j) = \frac{w_i}{p_i} \exp\left(-\frac{\max\left(d_i - p_i - t, 0\right)}{K_1\overline{p}}\right) \exp\left(-\frac{s_{ji}}{K_2\overline{s}}\right) \exp\left(-\frac{1}{APD_i\overline{s}}\right) \tag{14}$$

where $I_{ATCS\_APDi}(t, j)$ is the index for job i at time t, given that job j is the last one completed on the machine just freed. The ATCS_APD is also used to estimate the urgency of scheduling that job as ATCS. The job with the highest ATCS_APD index is considered to have the highest priority. The values of K_1 and K_2 are also obtained from equations (12) and (13), respectively, and APD_i is computed from equation (10). A job possessing a smaller APD_i should be assigned towards the beginning of the schedule; therefore, the APD_i is added in the denominator of the last term. The detailed steps of implementing the ATCS_APD dispatching rule are given below:

Step 1. For each job i calculate the APD_i index and set $t = 0$.

Step 2. Choose the machine k that is available at time t and compute the $I_{ATCS\_APDi}(t, j)$ for each job i that is unscheduled. If more than one machine is available at time t, then choose one arbitrarily.

Step 3. The job i with the highest $I_{ATCS\_APDi}(t, j)$ is assigned to machine k and set the time t as the loading time of machine k. If there are still unscheduled jobs, then go to *Step 2*; otherwise, stop.

Example 3

Also, referring to the data in the case plant (see Table 2), the ATCS_APD dispatching rule leads to the final schedule $M_1 = (J_{10}, J_2, J_7, J_5, J_1)$ and $M_2 = (J_3, J_8, J_9, J_6, J_4)$ with $\sum T = 81$ minutes. The corresponding Gantt charts of both schedules are shown in Fig. 4. The objective value obtained from ATCS_APD is quite close to the objective value of the optimal schedule. Many computational experiments and statistical analyzes will be conducted in the next section, such that the performance of the ATCS_APD can be demonstrated.

6. Computational results

To evaluate the performance of the proposed dispatching rule and the current method, extensive computational experiments are conducted. The current scheduling method, ATCS dispatching rule and the proposed ATCS_APD dispatching rule were coded in JAVA and executed on an Intel Core 2 Quad CPU Q8300 2.5 GHz PC with 2.00 GB RAM. The MIP was coded in commercial software ILOG CPLEX solver on the same computer. The considered parallel machine problem can be solved optimally by the MIP. Therefore, two sets of experiments are conducted: the first experiment is to evaluate the effectiveness of the current method (CM), ATCS, and ATCS_APD with the optimal solutions from the MIP for small-sized problems ($n = 10$); the second is to compare the ATCS and CM with the ATCS_APD for demonstrating the performance of the ATCS_APD.

6.1 Problem instance data generation

All the problem instances were randomly generated from discrete uniform distributions but with four different parameters. The number of machines is set to between two and four ($m = 2,3,4$), and the number of jobs is set to between 10 and 100 ($n = 10, 20, 50, 100$). The processing times of all test instances are generated from the discrete uniform distribution [180, 680], which is adjusted based on the case plant. The number of attributes is five: marking, hardness, width, color, and thickness. The attribute setup times are set to $S_1 = 60$, $S_2 = 15$, $S_3 = 20$, $S_4 = 15$, and $S_5 = 10$. The due date tightness factor is set to $\tau = (0.5, 0.7, 0.9)$ and the due date range factor is set to $R = (0.2, 0.5, 0.8)$. Furthermore, the number of different levels of attribute (NL_a) are generated from discrete uniform distributions [2, 7], which are also set according to the case plant. With regard to setting the due dates, the makespan should first be estimated by $\hat{C}_{\max} = (\beta \overline{s} + \overline{p})\mu$, where β is the coefficient accounting for the increase in makespan due to setup times, which is given by $\beta = 0.4 + 10/\mu^2 - \eta/7$ (Lee and Pinedo, 1997). The average due date is calculated using $\overline{d} = \hat{C}_{\max}(1-\tau)$, such that the due dates can be generated from discrete uniform distributions: $[(1-R)\overline{d}, \overline{d}]$ with probability τ, and $[\overline{d}, \overline{d} + (\hat{C}_{\max} - \overline{d})R]$ with probability $1-\tau$.

Therefore, 108 different combinations of four factors: m, n, τ, and R, are generated. For each combination, ten replications are generated randomly.

6.2. Experiment 1: Comparisons with the optimal solutions from MIP

In the first experiment, the MIP from Section 3 is conducted in commercial software ILOG CPLEX solver to obtain the optimal solutions for small-sized problems (i.e., $n = 10$). Then, the ATCS, ATCS_APD, and CM are implemented for each test instance. A measure called Normalized Relative Error (NRE), developed by

Lee and Pinedo (1997), is used to evaluate the three heuristics. The NRE is calculated as

$$\mathrm{NRE} = \frac{T(heuristic) - T(OPT)}{n\bar{w}\tau^2 \widehat{C}_{\max} / 2}, \tag{15}$$

where $T(heuristic)$ and $T(OPT)$ denote the total tardiness obtained from one of the three heuristics and the optimal solution from the MIP, respectively. The CPU time (in seconds) from the MIP and the average NRE of each combination are both shown in Table 3. Note that the CPU times of executing the three heuristics are not represented in this table, because these three heuristics take only one second to solve each instance. The italic and bold values of the average NRE in Table 3 show the equally good and better solutions among the three algorithms, respectively. From this table we observe that the average NER of the ATCS and ATCS_APD are both obviously better than that of CM in all combinations. Also, the average NRE (0.049) of ATCS is better than that (0.060) of ATCS_APD when the number of machines is two. However, the average NREs (0.044, 0.037) of ATCS_APD are better than that (0.046, 0.046) of ATCS when the number of machine is three and four. Furthermore, almost all the instances (217 from 270) can be solved by the MIP with a reasonable computational time; within 570.50 seconds on average.

6.3. Experiment 2: Comparison of three heuristics

To investigate the effectiveness and efficiency of the proposed ATCS_APD, it is compared with ATCS and CM. In this experiment, the test problem sizes are generated with the number of jobs $n = 10, 25, 50, 100$. The measure is also adopted by equation (15), which is calculated as:

$$\mathrm{NRE} = \frac{T(\text{ATCS or CM}) - T(\text{ATCS\_APD})}{n\bar{w}\tau^2 \widehat{C}_{\max} / 2}, \tag{16}$$

where $T(\text{ATCS or CM})$ and $T(\text{ATCS\_APD})$ denote the total tardiness obtained from one of either ATCS and CM and from the proposed ATCS_APD, respectively. The average NREs of each combination are summarized in Tables 4 and 5, and the italic and bold values also show the equally good and better solutions between the both heuristics, respectively. From Table 4, it is very significant that ATCS_APD outperforms the CM in each combination, as all the values of average NRE are positive. The average NREs are from 12.034% to 40.063%, which means that the ATCS_APD can improve the current method by at least 12.034% in dealing with the total tardiness. If the case plant applies the ATCS_APD for scheduling the jobs, the total tardiness penalties in the case plant could decreases at most by 40.063%. With regard to the CPU time, both ATCS_APD and CM take almost no time due to their simplicity.

Furthermore, although ATCS is widely used for solving the $Pm / s_{ij} / \sum T_i$ problem, the index does not involve the adjacent processing time and due date index, which is only calculated for the case problem. In Table 5, the comparison between ATCS and ATCS_APD is conducted. The experimental results show that ATCS_APD is better than ATCS especially in solving large-sized problems (i.e., $n = 20, 50, 100$). Moreover, to evaluate statistically the gap between the proposed ATCS_APD and the ATCS, a hypothesis test (*z*-test) is also conducted. Let μ_{ATCS_APD} and μ_{ATCS} be the average of the total tardiness and set null hypothesis $H_0 : \mu_{ATCS\_APD} - \mu_{ATCS} \geq 0$, alternative hypothesis $H_1 :$ $\mu_{ATCS\_APD} - \mu_{ATCS} < 0$, and significance level $\alpha = 0.01$. Table 5 also summarizes the computational results for all the problems. The *z*-value in Tables 5 means the test statistic. The test is to reject the hypothesis that the proposed ATCS_APD is worse than the ATCS, if and only if, the *z*-value is less than -2.33 for $\alpha = 0.01$. As almost all the *z*-values are less than -2.33 in Table 5, there is sufficient evidence to support the claim that the proposed dispatching rule is better than the ATCS. Therefore, we can conclude that the proposed ATCS_APD produces better quality solutions than the ATCS.

7. Conclusions and future research

In this paper, we have addressed an identical parallel machines scheduling problem with multi-attribute setup times for minimizing total tardiness originating from a plant producing PVC leather. As tardiness of the PVC leather products will lead to extra penalty costs and opportunity losses during peak season, the schedule manager in the plant has to have strict control over the tardiness in order to reduce the loss of revenue. No previous work has dealt with the total tardiness scheduling problem with multi-attribute setup times on parallel machines. In addition, the current method is basically an intuitive procedure, and there is a lack of well-defined sequencing rules to be used to improve the schedule systematically. Therefore, it is necessary to develop a heuristic to provide a near-optimal solution for the problem.

We have proposed a constructive heuristic based on the main concept of the apparent tardiness cost with setups (ATCS) dispatching rule (Lee and Pinedo, 1997) for the real-life problem, called ATCS_APD. The proposed heuristic considers simultaneously the least flexibility first rule, processing times, due dates, and the ATCS. The experimental results show that ATCS_APD outperforms the CM by a significant margin. The average improvements are from 12.034% to 40.063%, which means that the ATCS_APD could improve the current method by at least 12.034% and at most by 40.063% in dealing with the total tardiness. Furthermore, the statistical evaluation indicates that the proposed ATCS_APD can perform better than the ATCS, especially in solving large-sized problems. In summary, the proposed ATCS_APD heuristic has a conceptually easy design and can solve large problems with very short computation time. The ATCS_APD heuristic is more effective and efficient than the CM and the ATCS.

The actual capacity of the case PVC leather plant is about 14.4 million yards per year (i.e., about 1.2 million yards per month on average) with approximately 55.2 million U.S. dollars in annual revenue. In general, the output during peak season is estimated as probably 1/5 of the annual capacity with a total value of about 11 million

U.S. dollars. According to the past experience of the schedule manager, the relevant losses related to tardiness can be estimated as 4% of the total value during peak season, i.e., about 440 thousand U.S. dollars. From an application viewpoint, if the proposed ATCS_APD heuristic was applied in the case plant, it might be predicted that the plant could reduce losses of annual revenue from between approximately 53 to 176 thousand U.S. dollars. This will be a significant performance improvement for the schedule manager in the plant. Because the management is satisfied with the results of the proposed heuristic, it will be arranged to be tested in the scheduling system of the case plant in the near future.

Further research might be conducted to consider some other factors in the practical production system, such as machine breakdowns. It is also worthwhile to develop a scheduling method for identical or unrelated parallel machine problems with variable multi-attribute setup times.

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Table 1. Standard attribute setup times in the PVC leather plant

Attribute	Marking	Hardness	Width	Color	Thickness
Setup time (min.)	60	20	15	15	10

Table 2. A real case with 10 jobs

Attribute	Job 1	2	3	4	5	6	7	8	9	10	Attribute setup time
Marking (no.)	270	002	002	270	270	270	002	002	191	002	60
Width (inch)	30	52	42	52	52	30	52	70	52	42	15
Thickness (mm)	0.8	1.0	0.9	1.8	0.8	0.9	0.8	0.9	0.9	1.0	10
Hardness (no.)	7	8	9	8	7	9	7	9	9	7	20
Color (no.)	1	1	2	2	2	1	9	1	1	2	15
p_i (min.)	444	189	474	313	644	253	578	645	459	361	in minutes
d_i (min.)	2315	2087	1614	2463	2037	2275	2142	1693	1754	1596	

Table 3. Comparative results for the solution of three heuristics with optimal solution for small-size problem (i.e., $n = 10$)

		NRE			CPU Time	NRE			CPU Time	NRE			CPU Time
T	*R*	ATCS	ATCS_APD	CM	MIP	ATCS	ATCS_APD	CM	MIP	ATCS	ATCS_APD	CM	MIP
	0.2	**0.109**	0.114	0.392	938.31^{7}	0.105	**0.070**	0.124	206.78	0.171	**0.068**	0.096	241.31
0.5	0.5	**0.080**	0.110	0.221	777.15^{1}	**0.053**	0.081	0.153	33.61	**0.026**	0.048	0.129	257.65
	0.8	**0.049**	0.076	0.269	173.52^{1}	0.040	**0.024**	0.151	84.81	**0.030**	0.038	0.194	157.62
	Avg.	**0.079**	0.100	0.294	629.66	0.066	**0.058**	0.143	108.40	0.076	**0.051**	0.140	218.86
	0.2	**0.047**	0.055	0.219	1234.06^{7}	**0.067**	0.070	0.202	514.25	0.060	**0.046**	0.164	1249.20^{5}
0.7	0.5	0.063	**0.053**	0.286	1010.66^{3}	0.043	**0.042**	0.218	434.43	**0.032**	0.039	0.173	839.56^{2}
	0.8	**0.032**	0.040	0.221	697.22^{2}	**0.033**	0.043	0.297	315.66	0.036	**0.033**	0.201	743.61^{2}
	Avg.	**0.047**	0.049	0.242	980.65	**0.048**	0.052	0.239	421.45	0.043	**0.039**	0.179	944.12
	0.2	**0.019**	0.027	0.258	956.30^{2}	*0.027*	*0.027*	0.208	520.81^{1}	*0.021*	*0.021*	0.205	1308.27^{6}
0.9	0.5	**0.023**	0.034	0.234	1298.06^{1}	0.025	**0.017**	0.213	624.26^{1}	0.027	**0.024**	0.212	1187.46^{7}
	0.8	**0.019**	0.031	0.217	951.90	**0.022**	0.025	0.198	505.24	**0.010**	0.012	0.121	339.22^{5}
	Avg.	**0.020**	0.031	0.236	1068.75	0.025	**0.023**	0.206	550.10	*0.019*	*0.019*	0.179	944.98
	Agg.	**0.049**	0.060	0.257	893.02	0.046	**0.044**	0.196	359.98	0.046	**0.037**	0.166	702.66

Note: The superscript denotes the number of problems unsolved in 1,800 seconds from MIP by the ILOG CPLEX.

Table 4. Comparative results with ATCS_APD approach and current method

		m	2					3					4				
T	*R*	*n*	10	20	50	100	Avg.	10	20	50	100	Avg.	10	20	50	100	Avg.
0.5	0.2		28.302	21.699	26.028	42.866	46.625	1.941	11.163	24.180	42.306	47.552	-7.485	1.818	16.894	38.204	43.468
	0.5		14.065	13.298	32.119	34.009	39.214	10.055	5.330	28.552	31.082	39.845	10.312	9.630	13.879	27.195	52.312
	0.8		22.030	18.399	24.164	35.702	26.335	11.160	25.314	32.989	27.579	27.572	16.402	21.410	20.430	38.709	53.244
	Avg.		21.465	17.799	27.437	37.525	37.391	7.719	13.936	28.573	33.656	38.323	6.410	10.953	17.067	34.703	49.675
0.7	0.2		17.262	19.491	26.268	35.510	35.658	13.480	17.792	28.341	35.956	40.951	10.390	14.447	26.536	35.254	35.550
	0.5		22.337	20.402	30.152	30.354	37.869	17.482	17.453	21.621	28.793	35.999	14.065	18.541	19.529	32.894	38.406
	0.8		18.894	27.975	27.962	32.000	27.098	26.399	20.448	27.262	29.403	34.864	16.560	15.185	17.317	33.953	42.062
	Avg.		19.498	22.623	28.127	32.621	33.542	19.120	18.564	25.741	31.384	37.271	13.672	16.058	21.127	34.033	38.673
0.9	0.2		23.931	20.328	28.852	30.233	29.971	18.092	18.365	22.205	27.843	30.836	18.453	17.681	20.720	28.746	34.194
	0.5		21.150	16.452	22.417	31.286	28.768	18.779	23.545	22.007	31.027	31.082	18.435	14.905	26.453	29.178	28.388
	0.8		19.769	17.384	21.975	29.171	27.219	17.550	14.575	24.266	26.338	30.285	11.171	12.921	23.661	31.459	32.946
	Avg.		21.617	18.055	24.415	30.230	28.653	18.140	18.828	22.826	28.403	30.735	16.020	15.169	23.612	29.794	31.843
	Agg.		20.860	19.492	26.660	33.459	33.195	14.993	17.110	25.714	31.148	35.443	12.034	14.060	20.602	32.843	40.063

Table 5. Comparative results with the proposed ATCS_APD approach and ATCS approach

	m	2					3					4				
T	*R*	*n* 10	20	50	100	Avg.	10	20	50	100	Avg.	10	20	50	100	Avg.
0.5	0.2	**0.558**	-0.101	**2.463**	**0.853**	**0.491**	-3.460	**0.499**	**2.196**	-0.429	-1.571	-10.234	**0.626**	**0.693**	**1.289**	-2.774
	0.5	**2.952**	**0.151**	**1.487**	**1.580**	**1.731**	**2.828**	**0.535**	**0.029**	**0.777**	-0.323	**2.185**	-0.600	-0.103	**0.122**	**0.538**
	0.8	**2.785**	**1.922**	**0.481**	**0.780**	**0.757**	-1.570	**4.505**	**0.787**	**0.282**	**0.938**	**0.791**	**2.259**	**0.527**	**2.508**	**1.174**
	z-value	-3.952^{+}	-1.831	-5.803^{+}	-5.661^{+}		1.368	-3.262^{+}	-4.275^{+}	-1.083		2.628	-1.425	-1.754	-5.624^{+}	
	Avg.	**2.098**	**0.657**	**1.477**	**1.071**	**0.993**	-0.734	**1.846**	**1.004**	**0.210**	-0.319	-2.419	**0.762**	**0.372**	**1.306**	-0.354
0.7	0.2	**0.812**	**1.884**	**2.708**	**0.330**	**1.562**	**0.251**	**1.220**	**1.765**	**1.660**	**0.694**	-1.423	-0.972	**1.635**	**0.082**	**0.593**
	0.5	-1.051	**1.095**	-0.020	**1.248**	**0.753**	-0.136	**1.487**	**1.022**	**0.853**	**0.283**	**0.759**	-1.084	**2.100**	**1.485**	**1.035**
	0.8	**0.853**	**1.236**	**0.337**	**0.627**	**0.475**	**0.994**	**2.078**	**0.377**	**1.124**	**0.880**	-0.250	-0.126	**0.629**	**1.205**	**0.499**
	z-value	-0.809	-5.447^{+}	-5.285^{+}	-6.586^{+}		-1.517	-5.721^{+}	-5.602^{+}	-8.981^{+}		1.173	3.212	-7.227^{+}	-5.374^{+}	
	Avg.	**0.205**	**1.405**	**1.008**	**0.735**	**0.930**	**0.370**	**1.595**	**1.055**	**1.212**	**0.619**	-0.305	-0.727	**1.454**	**0.924**	**0.709**
0.9	0.2	**0.812**	**0.150**	**0.613**	**0.545**	**0.724**	-0.094	**0.930**	**0.129**	**0.257**	**0.423**	**0.030**	**0.434**	-0.050	**0.115**	**0.070**
	0.5	**1.103**	**1.446**	**0.572**	**0.540**	**0.858**	-0.803	**0.319**	**0.513**	**0.416**	**0.239**	-0.343	**1.362**	-0.129	**0.007**	**0.133**
	0.8	**1.180**	**0.236**	**0.329**	**0.460**	**0.556**	**0.306**	-0.054	**0.253**	**0.530**	**0.137**	**0.235**	**0.535**	**0.117**	**0.214**	**0.178**
	z-value	-5.598^{+}	-3.693^{+}	-5.817^{+}	-10.280^{+}		1.816	-2.915^{+}	-3.718^{+}	-5.396^{+}		-0.029	-7.426^{+}	0.341	-1.543	
	Avg.	**1.032**	**0.611**	**0.505**	**0.515**	**0.713**	-0.197	**0.398**	**0.299**	**0.401**	**0.266**	-0.026	**0.777**	-0.021	**0.112**	**0.127**
	z-value	-3.354^{+}	-3.746^{+}	-5.560^{+}	-7.293^{+}		0.409	-3.989^{+}	-4.560^{+}	-5.170^{+}		1.572	-1.289	-3.297^{+}	-4.212^{+}	
	Agg.	**1.112**	**0.891**	**0.997**	**0.774**	**0.878**	-0.187	**1.280**	**0.786**	**0.608**	**0.189**	-0.917	**0.270**	**0.602**	**0.781**	**0.161**

Note: The z-value with the + symbol means rejecting the hypothesis with the significance level $\alpha = 0.01$.

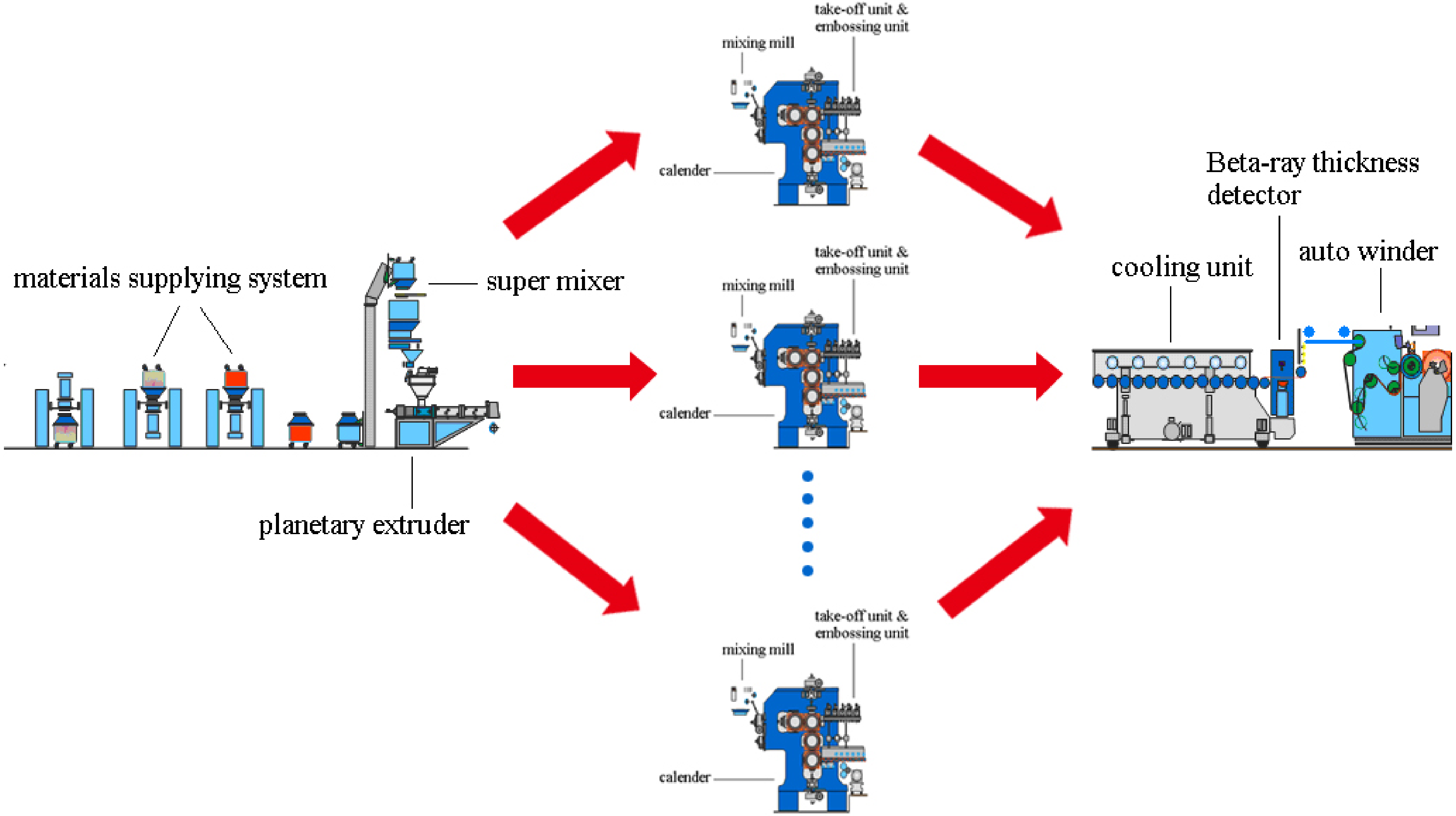

Figure 1. Production flow line of PVC leather plant

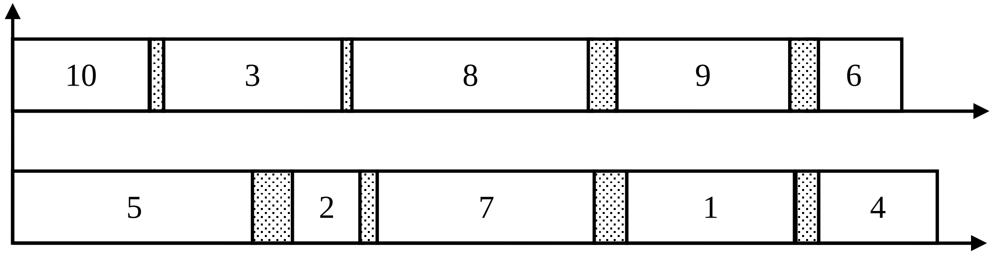

Figure 2. The schedule obtained by the current method with $\sum T = 447$.

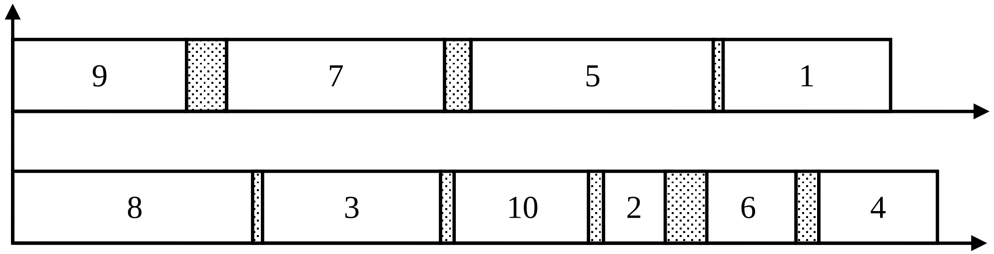

Figure 3. The optimal schedule from MIP with $\sum T = 52$.

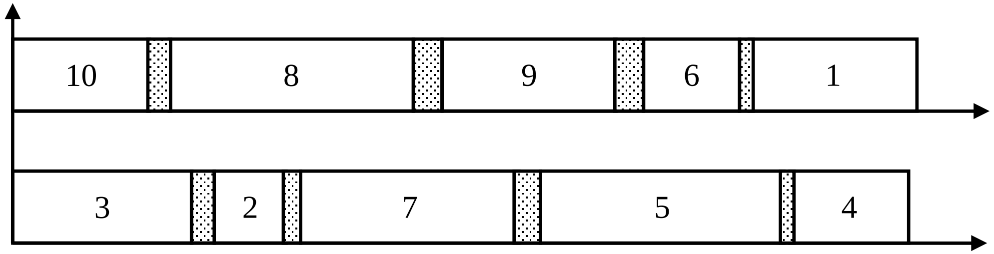

Figure 4. The schedule obtained by the ATCS approach with $\sum T = 115$.

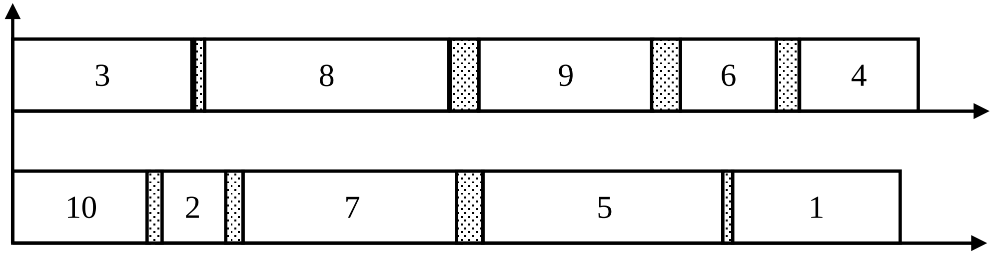

Figure 5. The schedule obtained by the ATCS_APD approach with $\sum T = 81$.

科技部補助計畫衍生研發成果推廣資料表

日期:2014/04/15

科技部補助計畫	計畫名稱: 聚氯乙烯膠皮工廠中總延遲時間最小化之排程問題
	計畫主持人: 李政雄
	計畫編號: 103-2410-H-263-001- 學門領域: 生產及作業管理
無研發成果推廣資料	

103 年度專題研究計畫研究成果彙整表

計畫主持人：李政雄
計畫編號：103-2410-H-263-001-
計畫名稱：聚氯乙烯膠皮工廠中總延遲時間最小化之排程問題

成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	0%	篇	
		研究報告/技術報告	0	0	0%		
		研討會論文	0	0	0%		
		專書	0	0	0%		
	專利	申請中件數	0	0	0%	件	
		已獲得件數	0	0	0%		
	技術移轉	件數	0	0	0%	件	
		權利金	0	0	0%	千元	
	參與計畫人力（本國籍）	碩士生	0	0	0%	人次	
		博士生	0	0	0%		
		博士後研究員	0	0	0%		
		專任助理	0	0	0%		
國外	論文著作	期刊論文	0	2	90%	篇	
		研究報告/技術報告	0	0	0%		
		研討會論文	0	1	80%		
		專書	0	0	0%	章/本	
	專利	申請中件數	0	0	0%	件	
		已獲得件數	0	0	0%		
	技術移轉	件數	0	0	0%	件	
		權利金	0	0	0%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	0%	人次	
		博士生	0	0	0%		
		博士後研究員	0	0	0%		
		專任助理	0	0	0%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

科技部補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性)、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標
□未達成目標（請說明，以 100 字為限）
　　□實驗失敗
　　□因故實驗中斷
　　□其他原因
說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：□已發表 ■未發表之文稿 □撰寫中 □無
專利：□已獲得 □申請中 ■無
技轉：□已技轉 □洽談中 ■無
其他：(以 100 字為限)

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性)(以 500 字為限)

首先感謝科技部補助此研究計畫，讓本研究順利如期完成。本研究計畫的研究成果茲簡要說明如下:

1.本研究計畫已產出兩篇學術期刊論文，目前皆已投稿至 SCI 國際學術期刊，並已 Under review。此二期刊為

Production planning & control 以及 International journal of production research。

2.本研究計畫所發展出來的演算法及派工法則，就學術價值而言，能明顯的改善現存方法的效果，且同樣僅需花費極短的計算時間，在效率上也極有價值。

3.本研究計畫的研究成果已獲得個案聚氯乙烯膠皮工廠的生產管理主管的重視，並將於不久後將本研究計畫的建議納入其排程系統中，預期未來應能提升工廠的整體效率，此部分為本研究具體的應用價值。