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# Application of SMED Methodology and Scheduling in High-Mix Low Volume Production Model to Reduce Setup Time: A Case of S Company

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**Abstract.** Nowadays rapid changes in consumer demand determines the production model. The demand for "single and large quantity" products has gradually turned into a "high-mix and low volume" product demand. The main problem of high-mix low volume model is significantly increasing frequency of set up, causing an increase in set-up time for production. For set-up reduction strategies, Shingo (1985) proposed single minute exchange of die (SMED) methodology. The SMED methodology makes it possible to reduce setup (changeover) operations time within 10 minutes. Therefore, in this study take a cable processing company as a case for improvement. The potential of faster setup cannot be completely achieved with SMED method. So, in this paper, it also provides an optimized scheduling reference indicator for the molding machine that decision makers to determine the sequencing rule of scheduling by each criterion through the system to achieve maximum benefit for company.

## 1. Introduction

Nowadays rapid changes in consumer demand determines the production model. Consumers require those few products with their specifications to meet the needs for functionality. Therefore, the demand for "single and large quantity" products has gradually turned into a "high-mix and low volume" product demand. The main problem of high-mix low volume model is significantly increasing frequency of set up. Setup time is nonproductive time and this also leads to high production costs [1]. So, the company must to adopt set-up reduction strategies to reduce the time for setup operations.

Shingo [2] proposed single minute exchange of die (SMED) methodology. The SMED methodology makes it possible to reduce setup operations time within 10 minutes, and Shingo [2] also claimed that SMED is "a scientific approach to reduce set-up time that can be applied in any factory to any machine". However, others related things involved in the setup process such as operators and scheduling are rarely mentioned. Another way for reducing nonproductive time is to perform fewer time-consuming set-ups, this can be achieved by optimizing planning schedules [3].

The examined company's processing flow is divided into in-line processing and off-line processing. In-line processing is mostly carried out by manpower, and off-line processing is processed through the machine. In this study, the scheduling model and SEMD methodology will be developed and applied to off-line processing machines to reduce total setup time.

The problem of the case study is molding area has lot of products waiting to be molded everyday. And the company adopts first come first molding operation at present. So, this study will address the



parallel machine scheduling problem of molding machines so as to determine processing sequence on each machine to optimize the schedule.

Therefore, the objective of the study, primarily, adopting SMED method to make setup time reduction. The potential of faster setup cannot be completely achieved with SMED method. Thus, a sequencing model will be developed to help determine an optimal schedule for the molding machines. This scheduling problem is Np-hard. So, in this study the sequencing model will be developed based on the combination of various dispatching rules.

## 2. Literature Review

SMED methodology is one of lean manufacturing tools. The SMED methodology has been extensively implemented in various industries [4]. This technique was Shingo proposed, that make it possible to perform setup (changeover) operations time to finish within 10 minutes. Shingo divides the setup operation into two parts [2]:

- Internal setup: The setup operation that requires machine must be shut down.
- External setup: The setup operation that can be done while the machine is still running.

Briefly, achieving SMED method is to translate the internal setup operation into external setup operation and optimize the internal setup operation to reduce total setup time.

A successful implementing SMED also can have the following benefits:

SMED can bring many benefits for a company such as, reductions in terms of stock, WIP, batch size and movements, and, improvements on quality and production flexibility [2]. There are many other examples of SMED applications with greatly improved in different industries in the past decade. But, based on my personal knowledge, I have not found a study discussing the SMED method and scheduling to reduce setup time in cable processing industry as well.

Scheduling is a decision-making process primarily concerned with the allocation of jobs on machines at a specific time [5]. There are many ways to solve scheduling problems. Different methods have their own characteristics and suitable types of problems. The following two kinds of methods, such as the heuristic algorithm and the mathematical formulation.

Heuristic algorithm is a method that solves problems, learns, and finds through multiple logic calculations, judgment and experience basis. The heuristic algorithm proves that the solution is efficient and well, but it is not guaranteed to be the best solution.

Mathematical formulation, in the optimal solution method through mathematical programming, including integer programming, mixed integer programming, dynamic programming and other methods. The time and cost of solving through mathematical programming may grow exponentially with the complexity of the problem. But, Yassine Ouazene et al. [6] proposed mathematical formulation for assigning  $n$  different jobs to  $m$  identical parallel machines is also used to provide optimal solutions in reasonable computational times. The mathematical models for most scheduling situations, such as single machine, parallel machine, flow shop, job shop, presented herein can consequently be used to obtain optimal or near optimal solutions.

## 3. Implemented SEMD methodology

The goal is to find out the operations that take more time in the setup process and then explore new way to reduce the required time to perform a tool change in order to achieve the best result, in this case study, it must observe the actual process to determine its main problems and constraints. For operation analysis chart, the classification set of the five activities is identified in the process: Processing, Inspection, Transportation, Waiting, Storage. There are also records of individual working time to find problems and improvement points.

In this case the desirable measurement precision considered with trust level of 95% for which  $z=1.96$ , and standard error of 5%. Given the average and standard deviation of the setup times obtained after

observing, 36 setup time observations were collected, and the results are recorded in Figure 1.

Date: 10-Jul-18		<input checked="" type="checkbox"/> 工作者 <input type="checkbox"/> 工作物	Operation Analysis Chart						Responsible:																					
Topic	Molding Machine	Processing ○	Inspection □	Waiting D	Transportation →	Storage ▽	#	labor	time(s)	distance(m)	fixture																			
		Current	12	1	1	2	0	16	1	1562	73	8																		
		Proposed	11	1	1	2	0	15	1	1239	48	7																		
Place		Save	1	0	0	0	1	0	323	25	1																			
Current												Proposed																		
#	Processing	Inspection	Waiting	Transportation	Storage	Operation Descriptin					labor	time(s)	distance(m)	fixture	#	Processing	Inspection	Waiting	Transportation	Storage	Operation Descriptin					labor	time(s)	distance(m)	fixture	
	○	□	D	→	▽											○	□	D	→	▽										
1				●		Take plastic materials					1	85	48	1	1				●		Take plastic materials					1	85	48	1	
2	●					Pour raw material into the feed port						192			2	●					Pour raw material into the feed port						192			
3	●					Machine parameter setting						63			3	●					Machine parameter setting						63			
4				●		Take Mold						96	25	1	4				●		Take Mold						20		1	
5	●					Diagonal mold removal						176		1	5	●					Diagonal mold removal						176		1	
6	●					Pull up machine						9			6	●					Pull up machine						9			
7	●					Lower corner mold removal						164		1	7	●					Lower corner mold removal						164		1	
8	●					Calibrate the mold inlet						247		1	8	●					Pull up machine						9			
9	●					Pull up machine						9			9	●					Template pressing						8			
10	●					Template pressing						8			10	●					Lock mold lower part						63		1	
11	●					Lock mold lower part						63		1	11	●					Lock mold upper part						79		1	
12	●					Lock mold upper part						79		1	12	●					Tuning parameter						27			
13	●					Tuning parameter						27			13			●			Washing plastic materials						138			
14				●		Washing plastic materials						138			14	●					Injection empty film						191		1	
15	●					Injection empty film						191		1	15		●					Inspection						15		
16		●				Inspection						15																		

Figure 1. Operation analysis chart of molding machine

In setup operations, only steps 1 and 4 are belong to external elements changed. Both of these steps are transportation and carrying. Through the 5S method, the plastic material and mold storage area are marked and discharged clearly to reduce the time of searching material and molds. The results are shown in Figure 2



Figure 2. By doing 5S method for molds

In addition, in Figure 5, the step 8 takes the longest time for operating. Because the nozzle hole should be aligned with the mold inlet, and the operator needs to use a toothpick to calibrate, as shown in below (Figure 3).

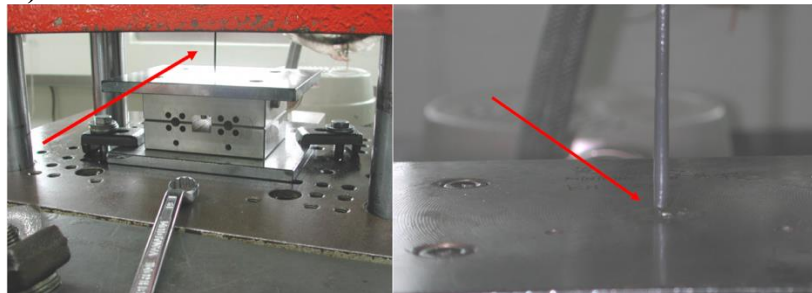
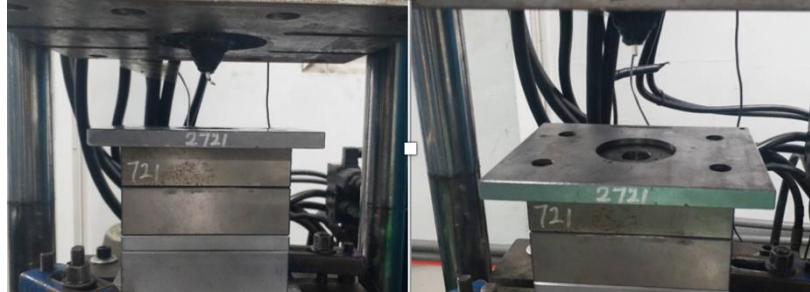


Figure 3. Align the inlet with a toothpick

The injection port is changed to a cylindrical shape, so when the machine is pulled down, the feed port can be aligned into the injection port directly, and the toothpick calibration operation is deleted, as shown in below (Figure 4).



**Figure 4.** Change injection port to cylindrical shape

By doing this, the step 8 can remove, because there is no need for calibration operation, once the machine is pulled down, the injection port can be aligned. It also can save a lot of time for setting up.

#### 4. Solution method of scheduling problem

The change of the selected parallel machine increases the difficulty and complexity of calculating the start time and finish time of each job on each machine. The parallel machine scheduling problem in this study is NP-hard. Therefore, this study solves the problem by considering the combination of various dispatching rules through a computer program coded in C++.

This study uses three sequencing rules, Shortest Setup Time (SSUT), Earliest Due Date (EDD) and Shortest Processing Time (SPT) and consider four criteria, i.e., Makespan, Total completion time, Total tardiness and Total setup time as results.

##### 4.1. The pseudo code of system algorithm

**Input:** Number of machines, Machine start date, Machine (the machine number), otherwise (-1), Enter setup time matrix row wise, Enter job details starting from job, Enter job duration, due date

**Output:**

Makespan(day), Total completion time of each machine(min), Total tardiness(day), Total setup time(min)

**Process:**

Job run SSUT rule schedule

```
{ Job vector result;
  for (unsigned job)
    if (job MachinePriority is -1 )
      Then select the job with shortest_setup_time}}
```

Job run EDD rule schedule

```
{ for (unsigned job) {
  if (job MachinePriority is -1 )
    Then select the job with earliest due date}}
```

Job run SPT rule schedule

```
{ for (unsigned job) {
  if (job MachinePriority is -1 )
    Then select the job with shortest processing time}}
```

Processor for schedule Jobs rule

```
{findNextToProcessMachine();
  machine which finish first
  switch (rule) {
  case Processor for SSUT:
    result = ssut_schedule(machine, jobs_);
```

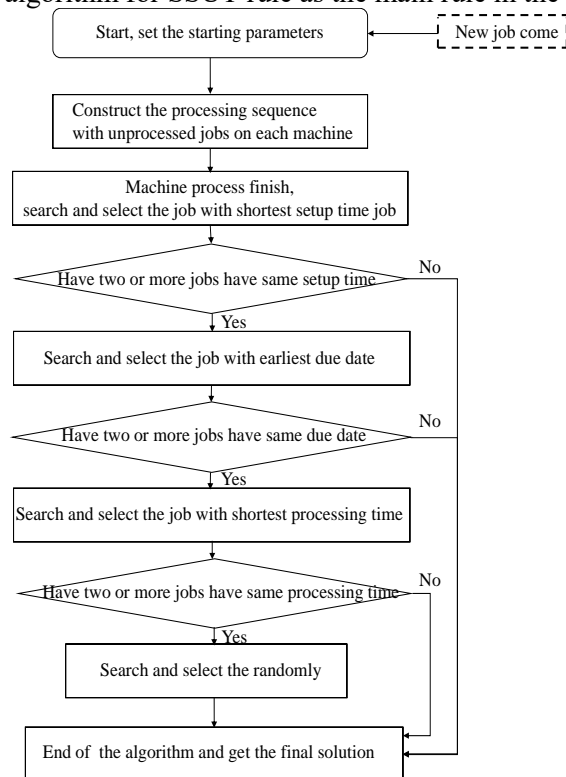
```

if have two or more job with same set up time
  then select the job with earliest due date }
if have two or more job with same due date
  then select the job with shortest processing time}
case Processor for SPT:
  result = spt_schedule(machine, jobs_);
if have two or more job with same shortest processing time
  then select the job with earliest due date}
if have two or more job with same due date
  then select the job with shortest setup time}
case Processor for EDD:
  result = edd_schedule(machine, jobs_);
if have two or more job with same due date
  then select the job with shortest processing time}
if have two or more job with same shortest processing time
  then select the job with shortest setup time}
If have new job come
  Add machine information and setup matrix size
  New Job will run each rule to compare with unprocessed jobs.
Machine Processor to find next ProcessMachine
{Machine will be allocated the job first by which machine finish processes first}

```

---

This chapter will give an example that base on the employed rules and the resulting outcomes. The following figure shows the algorithm for SSUT rule as the main rule in the sequencing model.



**Figure 5.** Using Shortest Setup Time sequencing rule process

The above figure only shows the combination of SSUT-EDD-SPT in that order, when SSUT rule is used as the main rule. Accordingly, if SPT rule is used as the main rule, then the order will be SPT-EDD-SSUT; and if EDD rule is used as the main rule, then the algorithm will be EDD-SPT-

SSUT. It is noted when EDD is not in the first order, it will be selected as the second rule because the company considers due date to be an important criterion.

#### 4.2. Illustrative Example

Assume that there are 3 machines and 6 jobs in the system, the matrix of setup time will be created in below (Table 1), and jobs information is shown in below (Table 2).

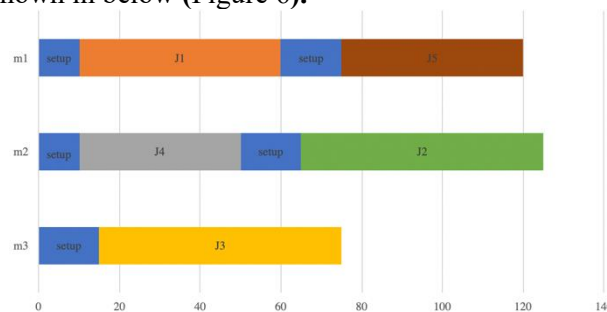
**Table 1.** Matrix of each job set up time (mins)

	$J_0$	$J_1$	$J_2$	$J_3$	$J_4$	$J_5$	$J_6$
$J_0$	-	15	20	20	25	20	25
$J_1$	15	-	15	15	15	20	20
$J_2$	20	15	-	25	20	20	25
$J_3$	20	15	25	-	15	20	20
$J_4$	15	25	20	15	-	25	25
$J_5$	20	20	20	20	25	-	20
$J_6$	25	20	25	20	25	20	-

**Table 2.** Information of each job

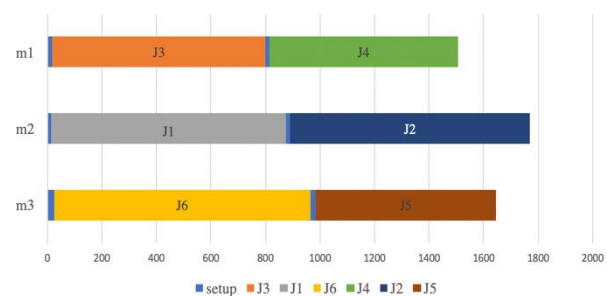
	$J_1$	$J_2$	$J_3$	$J_4$	$J_5$	$J_6$
Processing Time	860	880	780	690	660	940
Due Date	19-03	21-03	19-03	20-03	22-03	19-03

If SSUT-EDD-SPT is used, the priority assignment based on shortest setup time, the scheduling result of the example is shown in below (Figure 6).



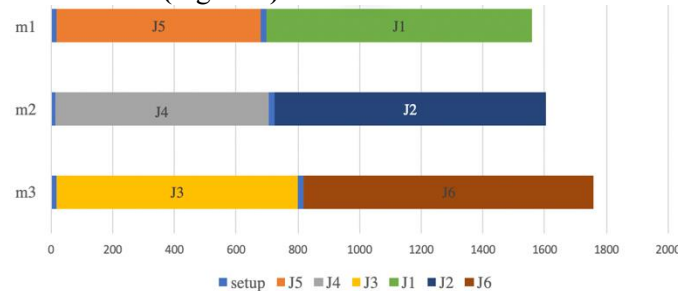
**Figure 6.** The schedule based on SSUT-EDD-SPT rule

If EDD-SPT-SSUT is used, the priority assignment based on earliest due date, the scheduling result of the example is shown in below (Figure 7).



**Figure 7.** The schedule based on EDD-SPT-SSUT rule

If SPT-EDD-SSUT is used, the priority assignment based on shortest processing time, the scheduling result of the example is shown in below (Figure 8).



**Figure 8.** The schedule based on SPT-EDD-SSUT rule

It is noted that different combinations of sequencing rules will give the four criteria different results. The job model assembled in programming code for output, the final sequence, it will be decided only by production manager who has the right to make the decision.

#### 4.3. Result Analysis

From the results of the example, the summary is presented in below (Table 3).

**Table 3.** The results of the example

		SSUT	EDD	SPT
Makespan (day / mins)		19-03-2019 1760	20-03-2019 1770	19-03-2019 1760
Completion time(mins)	M1	1505	1505	1560
	M2	1605	1770	1605
	M3	1760	1645	1760
Total setup time(mins)		110	110	115
Tardiness (days)		0	1	0

It is noted that, the commonly used performance measures include the following:

1. Makespan: The total amount of time required to complete a group of jobs is called makespan. Minimizing makespan supports the competitive priorities of cost and time.
2. Average flow time: A measure of the average time that a task spends in the system.

$$\text{Average flow time} = \frac{\text{Total flow time}}{\text{Number of jobs}} \quad (1)$$

3. Utilization: The degree to which equipment, space, or the manpower are currently being used, Maximizing the utilization of a process supports the competitive priority of cost (slack capacity).

$$\text{Utilization} = \frac{\text{Total job processing time}}{\text{Total flow time}} \quad (2)$$

4. Average number of jobs in the system: The number of jobs at each time point in the system to measures amount of work-in-progress.

$$\text{Average number of jobs in the system} = \frac{\text{Total flow time}}{\text{Total job processing time}} \quad (3)$$

5. Average job lateness: The average time that the jobs do not meet due date.

$$\text{Average job lateness} = \frac{\text{Total late days}}{\text{number of jobs}} \quad (4)$$

6. Setup cost: The total setup cost of the machines, which can be calculated through total setup time required in all operations.



**Table 4.** Summary on performance measures for each rule

Rules	Makespan (mins)	Average flow time (mins)	Utilization (%)	Average number of jobs in the system	Average job lateness (days)	Total setup time (mins)
SSUT	1760	1231.67	67	1.49	0.00	110
EDD	1770	1260.00	65	1.54	0.17	110
SPT	1760	1185.00	69	1.44	0.00	115

From the above table of performance measures, the ranking of each rule has different results. No one sequencing rule excels on all criteria. It is noted in this study that minimum setup time should be included in the scheduling rules. Since the setup time is non-productive time, but also requires manpower, there will be more costs and productivity also will decrease. However, in the pursuit of minimizing setup time, it may also cause delays in job, and may receive penalty from customers and lose customers' credit to the company. So, decision makers must evaluate the results carefully to achieve maximum benefit.

### 5. Conclusions and Recommendations

In this study, two methods of SMED and scheduling are proposed to reduce setup time. SMED methodology has proven to be effective in a variety of industries. It is also possible to shorten the setup times by the conventional SMED method. In this study, the SMED method was applied on the molding machine and setup time was reduced from 1562 to 1239 seconds. A gain of 20 percent was achieved, but there were setup activities that still have the ability to reduce more in term of setup time, but due to cost considerations, the company has not implemented yet.

Furthermore, in terms of scheduling, it is also possible to reduce the setup time by employing the appropriate mix of sequencing rule. But it may happen that company has to pay for additional costs while pursuing the minimum setup time. For instance, if the company employs the SSUT-EDD-SPT rule with minimum setup time as the main sequencing rule, it can be seen that the ranking of the SSUT-EDD-SPT rule is not the best in all performance measures, which may result in more additional costs. Therefore, in this study, a system was developed to allow decision makers to get scheduling results quickly after knowing job information. The resulting performance measures of different combinations of sequencing rules can help decision makers to make the decision so as to maximize the benefit for the company.

In the case study, many molds changerover operations involve the steps of unlocking and locking the screws. This leads to the fact that the machine should be shut down for a long time. The automatic and precise positioning of the clamp has been developed to effectively reduce the time and manpower of setup. The clamp can be applied in the future, so that the company can continue the drive towards greater flexibility and more efficient manufacturing environment.

Regard to scheduling, in the future, the research works can address other important factors like overall execution cost and load balancing during the scheduling process using sequencing rules. The results of performance measures can be converted into a unit of cost display, making it much easier for decision makers to choose a solution that minimizes costs.

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