東　　海　　大　　學

工業工程與經營資訊學系

碩士論文

少量多樣生產型態下導入 SEMD 與最佳化排程以縮短裝備時間-以 S 公司為例

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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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摘　　要

現今消費者需求的快速變化決定了工廠的生產模式。從過往的“少樣多量”的產品需求模式逐漸轉變為“多樣少量”的產品需求。在多樣少量的生產模式下，主要問題是顯著地增加換模頻率，這導致生產裝備時間的增加。對於裝備時間的減少策略，Shingo 學者於 1985 年提出了快速換模技術（SMED）方法。 該 SMED 方法可以減少裝備操作時間於 10 分鐘內。

因此，本研究以線材加工公司為案例進行改善。但應用 SMED 的方法並無法完全實現更快速地換模的潛力。因此，本研究簡化了成型機的優化排程參考績效指標，幫助決策者通過系統確定每個績效指標的排程規則，從而為公司創造最大利益。

關鍵字詞：多樣少量、快數換模技術、SMED、排程、數學模型、案例研究

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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, that leads an increase in set-up time for production. For set-up reduction strategies, Shingo (1985) proposed single minute exchange of die (SMED) method. The SMED method makes it possible to reduce setup operations time within 10 minutes. Therefore, this study takes a cable processing company as a case for improvement. The potential of faster setup cannot be completely achieved with SMED method. So, this study eases an optimized scheduling reference indicator for the molding machine that aid decision makers to determine the sequencing rule of scheduling by each criterion through the system to achieve maximum benefit for company.

Keywords：High-Mix and Low Volume, Single Minute Exchange of Die, Scheduling, Mathematical Model, Case Study

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CHAPTER 1 INTRODUCTION

1.1 Background

Mass production model is gradually being challenged. Nowadays rapid changes in consumer demand determines the production model. Consumers buy the products that are offered by companies, but they 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. Production model is also no longer standardized for mass production. So, customers' needs and expectation are addressed with company's flexibility on many production criteria. Hence flexibility plays an important role in all areas of industry (Bateman et al., 1999). Increased flexibility is one of the key factors in converting performance (McIntosh et al., 2001). The faster changer-over time increases the production time.

At same time, the main problem of high-mix low volume model is significantly increasing frequency of set up, causing an increase in total set-up time for production. The setup time is characterized as the time between subsequent to running the last task of present job and beginning to run the first task of next job. Setup consist of those activities like detecting equipment, fixtures or dies, inspection, and adjustment that aid to accomplish upcoming operational activities. (Azzi et al., 2012), and, changeover is a subset of setups. The changeover represents the elapsed time for detach and attach tool, dies or fixtures. Setup time and change-over time are often used interchangeably. Setup time is nonproductive time and due to this the productive time is wasted and this also leads to high production costs (Goubergen and Landeghem, 2002). So, company must adopt set-up reduction strategies to reduce the time for setup operations.

The reduction of setup time is mainly applied for flexible as well as lean manufacturing (Gung and Studel, 1990). Rapid changeover capability is critical fundamental technique of lean manufacturing for minimizing waste. This enhances responsiveness and flexibility in regard of manufacturing processes. So, Shingo (1985) proposed single minute exchange of die (SMED) method for flexibility technique. This method creates possibility to lower setup time within 10 minutes, and Shingo (1985) also stated that SMED is “a scientific approach to reduce set-up time that can be applied in any factory to any machine”. Conventional SMED method highlights the setup activities that are performed mostly to achieve perfection on machines (Ekincioğlu and Boran, 2017); however, others related things involved in the setup process such as operators and scheduling are rarely mentioned. Meanwhile nonproductive time is also reduced via efficient set-ups, along with optimizing planning schedules (e.g., determining an optimal scheduling sequence for diverse products). Sherali et al. (2006), McIntosh et al. (2000) suggested the SMED method effectivity depends on comprehensive knowledge on the possible improvement techniques. In this study, a cable processing company will be examined as a case study for further improvement. Such as application of SMED method to lessen total setup time.

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 outside the line. So, off-line processing machines scheduling problem should be considered. The scenario of workshop production is shown in Figure1.1.

In this study, mathematical models will be developed and applied to off-line processing machines to reduce total setup time.

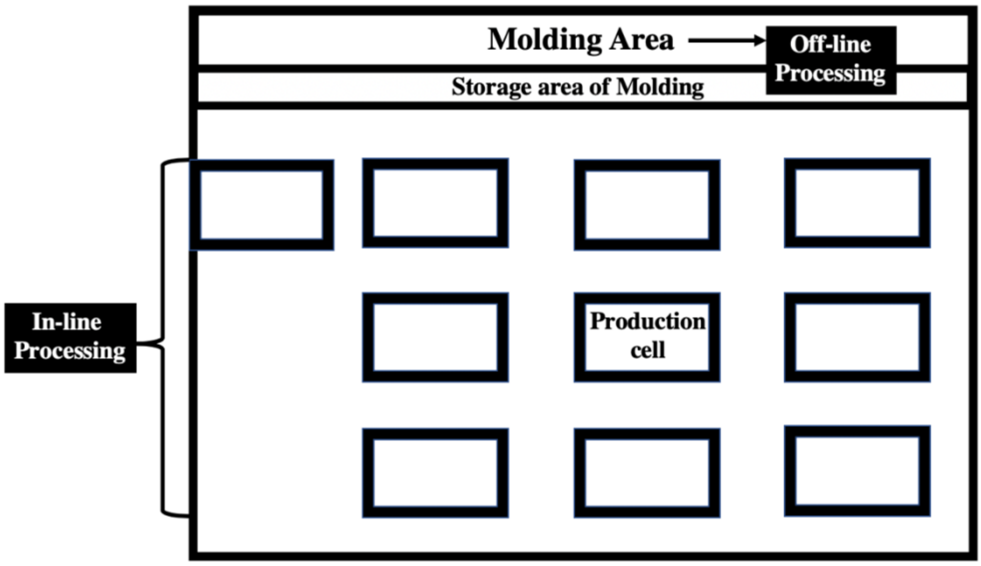

Figure 1.1 The scenario of workshop production

1.2 Statement of the Problems

In "high-mix and low volume" product demand environment, production of the examined company is as follows:

- Production control personnel will update daily schedule to plan for each production cell production in terms of manpower and product items required in every morning.
- In the shop floor, there are 10 production cells needed to produce around 30 products per day.
- Most of the products subject to be molded from off-line processing, with a total of 15 molding machines.
- Every product usually needs to be processed for pre-molding and over-molding, so the molding processing time is long and there are many products waiting for molding.

From above-mentioned information, the problem of this case study is after releasing of the daily schedule, each cell production team will start their own job (in the company, it is called in-line processing). After finishing in-line process, the products will be sent to molding area (off-line process) and waiting to be molded. The structure of off-line processing problem is shown in Figure1.2. In off-line processing, normally molding area will have lot of products waiting to be molded. 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 reduce setup time. In addition, the scheduling problem is to schedule all products within a given daily production plan to allocate jobs and determine processing sequence on each machine to optimize the schedule.

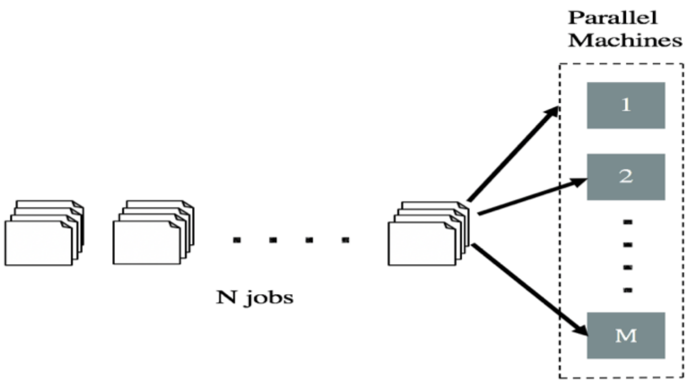

Figure 1.2 The structure of off-line processing problem

1.3 Objectives

The main goals for case company problem are as follows. Firstly, adopting SMED method and integrated lean manufacturing tool for molding machines to make setup time reduction and optimization of die changeover time within 10 minutes.

The potential of faster setup cannot be completely achieved with SMED method. Thus, in the case of the company under consideration, a sequencing model will be developed to determine an optimal schedule for the molding machines. The scheduling problem is Np-hard. Hany Seidgar et al., (2015) proposed a mathematical model to schedule flexible flow shop problem, which coincides with the objective of this study. Here meta-heuristic algorithm provides the best solution space and run numerical example that verifies the confirmation of this mathematical model application as expected. However, in this study the sequencing model will be developed based on the combination of various dispatching rules.

1.4 Scope and Limitations

The following assumptions and characteristics will be considered in this research:

- The scheduled molding machine environment is Parallel Machine.
- Each of the parallel machines only can process one job at a time.
- The scheduling problem is static.
- Each job has sequence dependent setup time.
- The information for each job is known and it can be scheduled at the same time.
- On every machine, the ready times that job can start processing are different.
- During the setup activities, only one operator will get involved and tasks cannot be split.

CHAPTER 2 LITERATURE REVIEW

This chapter explores the related literature review over the years, organizes the application of the SEMD method and the mathematical model of related scheduling problem to explains separately. Section 2.1, discusses the implementation of the SMED method and the improvement tool used in the past literatures, and explores the case company for this study is described; Section 2.2, the development of case scheduling, sort out the methods proposed by scholars in the past for scheduling problems. Solution method; Section 2.3, explain the mathematical model used in this study to solve the scheduling problem.

2.1 SMED Method

Lean manufacturing technique must be responsive to the rapid changes in consumer demand (Mehmet Cakmakci, 2009). As SMED method is a part of lean manufacturing tools, its application is profound in numerous industries. (Joshi and Naik, 2012). This Shingo proposed technique incorporates the possibility to complete setup operations to finish within 10 minutes. The setup operation is further classified into two categories (Shingo, 1985):

- Internal setup: The setup process which compulsory require the machine to halt its operation. (Such as locating or detaching the dies.)
- External setup: The setup process that can do parallelly along with machine in operation.

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: Company’s reduction in aspects of lot size and movements, stocks, WIP, and, enhancements on quality and production flexibility (Shingo,1985)

- Reduction in production cost (Decline in non-productive time as result of faster changeovers)
- Reduction in lot sizes (Speedier changeovers enable more frequent product

changes)

- Improvements on quality and production flexibility (Quick changeovers leads to flexibility to cope up with demand)
- Efficient startups (standardized changeover processes)
- Lesser inventory levels

Much more illustrations are abundant for SMED applications. Following table 2.1 shows authors using SMED and other improvement tools as a set-up time reduction with greatly improved in different industries in the past decade:

Table 2.1 SMED Application and result

Paper, Author	Applied industry	Methodology	Time Reduction
Improving SMED in the Automotive Industry: A case study. Ana Sofia Alves, Alexandra Tenera (2009)	Injection machines of automotive industry	SMED and other lean Manufacturing tools	Total 48% reduction
Setup time reduction: SMED-balancing integrated model for manufacturing systems with automated transfer. Maurizio Faccio (2013)	Pump producer with automated rotating transfer	Traditional SMED & Proposed SMED-workload balancing model	After SMED application reduction-59% After SMED-Balancing application Reduction-79%
Improving changeover time: a tailored SMED approach for welding cells. Pablo Guzmán Ferradás, Konstantinos Salonitis (2013)	Welding cell	New tailored SMED	33% reduction
Improvement of changeover times via Taguchi empowered SMED/case study on injection molding production. M. Kemal Karasu, Mehmet Cakmakci, Merve B. Cakiroglu, Elif Ayva, Neslihan Demirel-Ortabas (2014)	Plastic injection molding	Taguchi empowered SMED	30% overall reduction

Paper, Author	Applied industry	Methodology	Time Reduction
Reduction in Setup time on Rubber Moulding Machine using SMED Technique. Sanket P. Gaikwad, Shivprasad S. Avhad, Swapnil S. Pawar, Pradnya R.Thorat (2015)	Rubber Moulding Machine	SMED	2 hours to 8 mins
The contribution of lean manufacturing tools to changeover time decrease in the pharmaceutical industry. A SMED project. Al-Akel Karam, Marian Liviu, Veres Cristina, Horea Radu(2017)	Pharmaceutical Industry	SMED methodology, externalizing steps, visual management and Full Time Equivalent redistribution	33% overall reduction
SMED methodology based on fuzzy Taguchi method. Caner Ekincioğlu, Semra Boran (2018)	CNCx machines	Integrate the fuzzy Taguchi method into the SMED method	from 196 to 75 mins

Based on personal knowledge, it has not found a study discussing the SMED method and scheduling to reduce setup time in cable processing industry as well.

2.2 Scheduling

The job allocation process at specific time on a machine is called Scheduling. (Tavakkoli-Moghaddam and Daneshmand-Mehr, 2005). Various methods like Cutting Plane, Branch and Bound, Heuristic, Genetic Algorithm, Simulated Annealing, Machine Learning and many more are used to solve Scheduling problems. Therefore, there are many measures for scheduling performance, they can also be grouped into primarily two major categories. Table 2.2 Shaukat Ali Brah et al., (1991) provides a list of the most commonly considered criteria in the literature on scheduling.

Table 2.2 Criteria of Optimality Shaukat Ali Brah et al., (1991)

Category	Metrics
BASED ON COMPLETION TIME	Maximum/ Total/ Mean/ Weighted Sum of Flow Time Maximum/ Total/ Mean/ Weighted Sum of Completion Time Jobs Waiting Time Weighted Job Waiting Time
BASED ON DUE DATE	Maximum/ Total/ Mean/ Weighted Lateness Maximum/ Total/ Mean/ Weighted Tardiness Maximum/ Total/ Mean/ Weighted Earliness Number of Tardy Jobs/ Early Jobs

2.3 Scheduling problem solving method

As described in Section 2.2, 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. And, the time required for each solution will not be the same. In the past, many authors have proposed heuristic algorithms to solve scheduling problems in Table2.3.

Table 2.3 Heuristic algorithms of solving scheduling problems

Author	Scheduling environment	Solving method	Scheduling objective
Cintia Rigão Scrich, Vinícius Amaral Armentano, Manuel Laguna (2004)	Flexible job shop	Tabu search approach	Minimize total tardiness
Neto&Godinho (2011)	Flow Shop	Ant colony optimization approach	Multi-objective considerations
Shih-Wei, Lin & Kuo-Ching, Ying (2015)	Unrelated parallel machine	Simulated Annealing	Minimize make span, Total weighted completion time and tardiness

Author	Scheduling environment	Solving method	Scheduling objective
Young-BinWoo, Sunwoong Jung, Byung Soo Kim (2107)	Unrelated parallel machine	Genetic algorithm	Minimize makespan
Thi-Kien Dao, Tien-Szu Pan, Trong-The Nguyen, Jeng-Shyang Pan (2018)	Job shop	Bat algorithm	Optimize makespan

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, Shaukat Ali Brah et al., (1991) mentioned the mathematical formulation is simple and comprehensive enough to cover most measures of performance for scheduling. In addition, Yassine Ouazene et al., (2013) proposed mathematical formulation for assigning n different jobs to m identical parallel machines. It also offers optimal solutions in real computational times. Most of scheduling situations, such as single machine, parallel machine, job shop and flow shop presented herein can consequently be used to obtain optimal or near optimal solutions.

CHAPTER 3 METHODOLOGY

3.1 Overview

The following flowchart presents the method that would be implemented in order to achieve the research objective.

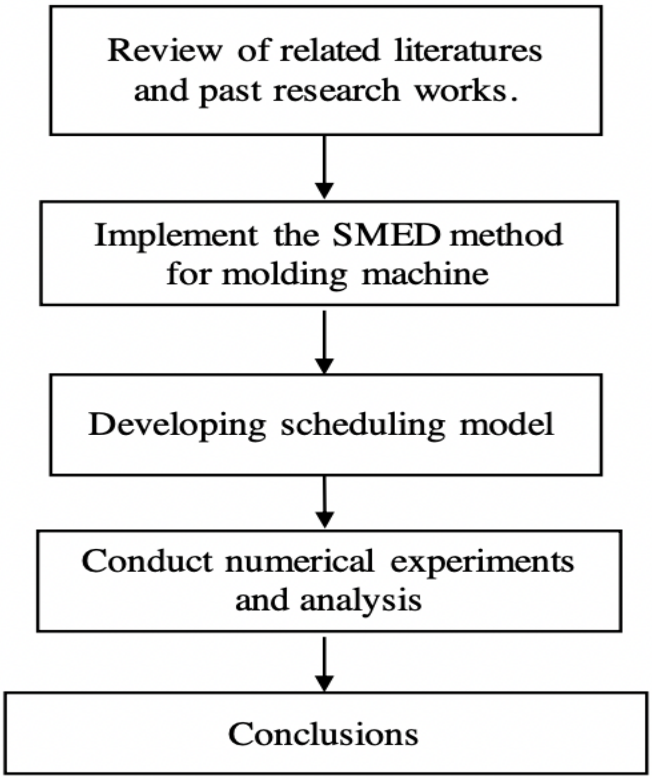

Figure 3.1 The methodology flowchart

3.2 Proposed SMED's Implementation Method

The correct identification of external and internal setup is the most critical success factors for SMED's implementation. Thus, to ensure it, following guideline should be considered:

Step 1: Identify Pilot Area
Step 2: Recognize all the elements as internal or external of setup
Step 3: Separate external elements and classify into three segments: external setup (Before changeover), internal setup (During changeover), and external setup (After changeover).
Step 4: Transform internal setup to external setup
Step 5: Streamline remaining elements

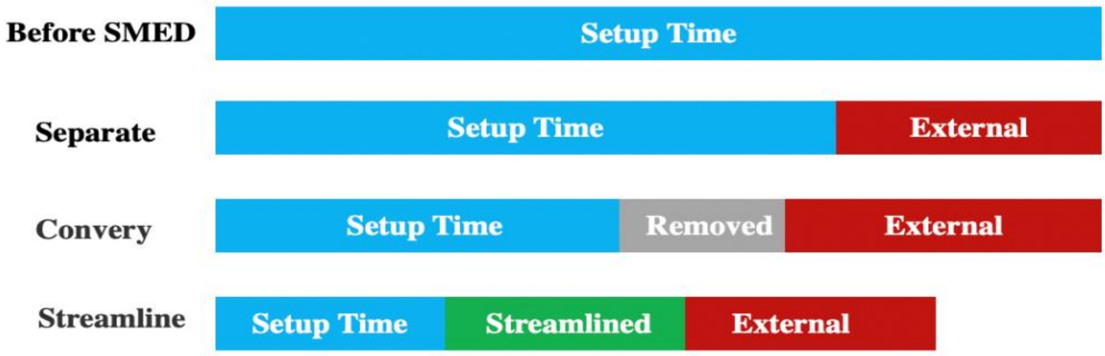

Figure 3.3 The Schematic Diagram of SMED implementation

Based on SMED's implementation there will be proposed a method which improves setup time. This is done majorly to find out the operations that take more time in the setup process and then explore new technique to lessen the required time of altering a tool for achieving the best result.

3.3 Data Gathering Procedure

In this process of data gathering, the below mentioned three stages are performed to achieve the desired pattern of data for analysis.:

1. Observation of the current changeover operations and working area
2. Interview with the team leader and the operators about the setup procedure
3. Documentation of the collected data (setup time)

While recording each time of the setup, it can observe critical points that reduce setup procedure as well. The recorded data for set up time is also given as input parameter for the scheduling system depending on the product type

3.4 Setup Operation Analysis Chart

The data collection requires the appropriate tools to obtain the analysis. In this case study, the major constraints and problems for actual process are observed and determined. The setup process is very complex, so it will adopt operation analysis chart to analyze each operation clearly. Alves and Tenera (2009) proposed and applied the operation analysis chart, it will characterize the process of changeover which exist on manufacturing process as an essential tool in its characterization. The operation analysis chart is necessary in characterizing the process of changeover, as it allows classification of all required activities for conducting this process. 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. Th operation analysis template applied here in the study is presented in Figure 3.3.

Date:		工作者 工作物 Operation Analysis Chart						Responsible:			
Topic			Processing ○	Inspection□	Waiting D	Transportation →	Storage ▽	#	labor	time(s)	distance(m)	fixture
		Current	0	0	0	0	0	0	0	0	0	0
		Proposed	0	0	0	0	0	0	0	0	0	0
Place		Save	0	0	0	0	0	0	0	0	0	0

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																					
2																					
3																					
4																					
5																					
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15																					
16																					

Figure 3.4 Operation analysis chart template

According to the operation analysis chart, it will be able to describe in details the time spent on each operation and the time spent in each group of operations. In order to resolve the operational parallelism in the transformation to distinguish between internal and external setup, the Gantt chart must also be integrated and applied.

3.5 Implemented solutions in case company

In the case study, the SMED Methodology of the molding machine is discussed, so the setup operations of the molding machine were observed and recorded first.

With 95% of trust level along with z=1.96, and standard error of 5%, the measurement precision in this case are observed.

Given the average and standard deviation of the setup times found later by observing, 36 setup time observations were collected, and the results are recorded in Figure 3.4.

☑ 工作者 ☐ 工作物 **Operation Analysis Chart**

Date: 10-Jul-18 **Responsible:**

			Processing ○	Inspection□	Waiting D	Transportation →	Storage ▽	#	labor	time(s)	distance(m)	fixture
Topic	**Molding Machine**	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**	**0**	**1**	**0**	**323**	**25**	**1**

Current

#	Processing ○	Inspection □	Waiting D	Transportation →	Storage ▽	Operation Descriptin	labor	time(s)	distance(m)	fixture
1				●		Take plastic materials	1	85	48	1
2	●					Pour raw material into the feed port		192		
3	●					Machine parameter setting		63		
4				●		Take Mold		96	25	1
5	●					Diagonal mold removal		176		1
6	●					Pull up machine		9		
7	●					Lower corner mold removal		164		1
8	●					Calibrate the mold inlet		247		1
9	●					Pull up machine		9		
10	●					Template pressing		8		
11	●					Lock mold lower part		63		1
12	●					Lock mold upper part		79		1
13	●					Tuning parameter		27		
14			●			Washing plastic materials		138		
15	●					Injection empty film		191		1
16		●				Inspection		15		

Proposed

#	Processing ○	Inspection □	Waiting D	Transportation →	Storage ▽	Operation Descriptin	labor	time(s)	distance(m)	fixture
1				●		Take plastic materials	1	85	48	1
2	●					Pour raw material into the feed port		192		
3	●					Machine parameter setting		63		
4				●		Take Mold		20		1
5	●					Diagonal mold removal		176		1
6	●					Pull up machine		9		
7	●					Lower corner mold removal		164		1
8	●					Pull up machine		9		
9	●					Template pressing		8		
10	●					Lock mold lower part		63		1
11	●					Lock mold upper part		79		1
12	●					Tuning parameter		27		
13			●			Washing plastic materials		138		
14	●					Injection empty film		191		1
15		●				Inspection		15		

Figure 3.5 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. In high-mix and low volume product demand, the company has many molds for products to mold. Therefore, through the 5S method (SEIRI, SEITON, SEISO, SEIKETSU, SHITSUKE), 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 3.5.

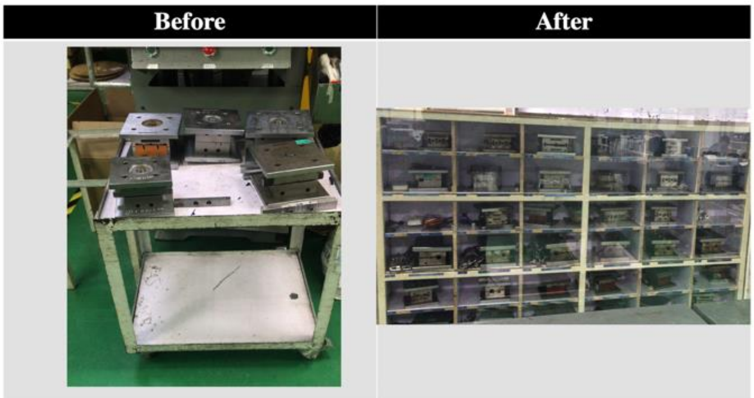

Figure 3.6 By doing 5S method for molds

In addition, in Figure 3.4 the operation analysis chart, 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 Figure 3-6.

Figure 3.7 Align the inlet with a toothpick

Therefore, by modifying the mold, the injection port is changed to a cylindrical shape, so when the machine is pulled down, the inlet can be aligned into the injection port directly, and the toothpick calibration operation is deleted, as shown in Figure 3.7.

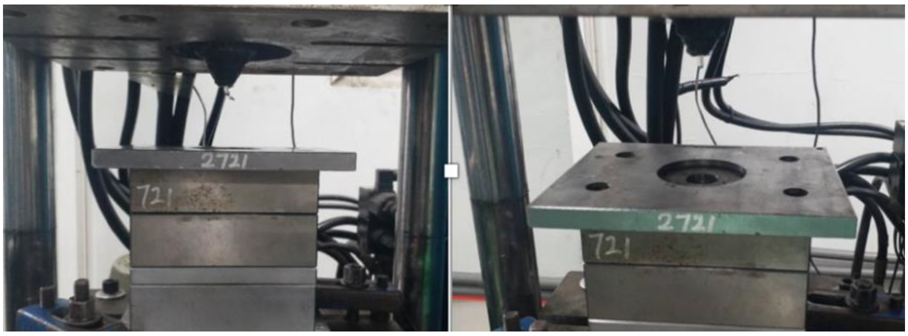

Figure 3.8 Change injection port to cylindrical shape

By doing this, step 8 can be removed, 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.

In addition, in the process of locking and unlocking of the mold, it is currently time-consuming and laborious to use the wrench to lock and unlock the screw. as shown in Figure 3.8. It was found that the method of locking the mold by magnetic or vacuum can be recommended to the company to reduce the time for locking and removing mold. But, the cost of changing the equipment of machine is too high, so the company has not yet done.

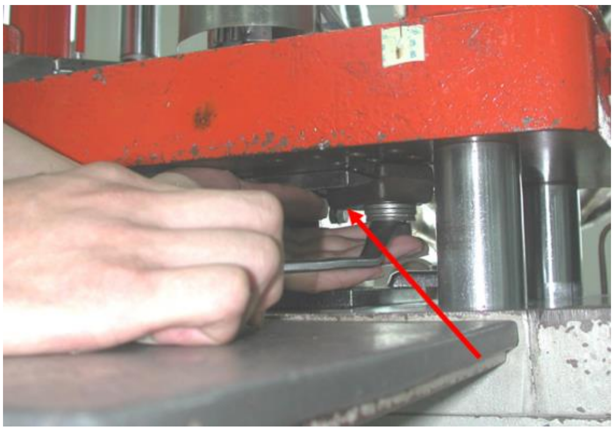

Figure 3.9 Operator uses the wrench to lock the screw

3.6 Solving Scheduling problem of molding machine

Reducing the molding machine setup time through the SMED method also provides a scheduling reference set of indicators for the molding machine that decision makers can use to determine the sequencing rule of scheduling by use of some criteria through the system. Detailed scheduling model will be presented in the following chapter.

CHAPTER 4 RESULT AND DISCUSSION

4.1 Scheduling Problem

The molding machine scheduling problem discussed in this study is defined as follows. Jobs are allocated to each machine to solve the optimum processing order of the jobs. The jobs are selected with parallel machines. The change of the selected 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++.

4.2 The pseudo code of system algorithm

Input: Number of machines
Machine start date
Enter setup time matrix row wise:
Enter job details starting from job
Enter job duration (minutes), due date(dd-mm-yyyy)
Output:

SSUT Result
Machine ID:
Jobs assigned:
1. Make span(day):
2. Total completion time of each machine(min):
3. Total tardiness(day):
4. Total setup time(min):

EDD Result
Machine ID:
Jobs assigned:
1. Make span(day):
2. Total completion time of each machine(min):
3. Total tardiness(day):
4. Total setup time(min):

SPT Result
Machine ID:

Jobs assigned:
1. Make span(day):
2. Total completion time of each machine(min):
3. Total tardiness(day):
4. Total setup time(min):

Enter the number of new jobs:

Process:

```
Job run SSUT rule schedule
{Job vector result;
    for (unsigned job)
        if (job Machine Priority is -1)
        Then select the job with shortest_setup_time}
Job run EDD rule schedule
{for (unsigned job) {
        if (job Machine Priority is -1)
        Then select the job with earliest due date}
Job run SPT rule schedule
{for (unsigned job) {
        if (job Machine Priority 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}
            break;
        case Processor for SPT:
            result = ssut_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}
            break;
        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 job.}
Machine Processor to find next Process Machine
{Machine will be allocated the job first by which machine finish processes first}

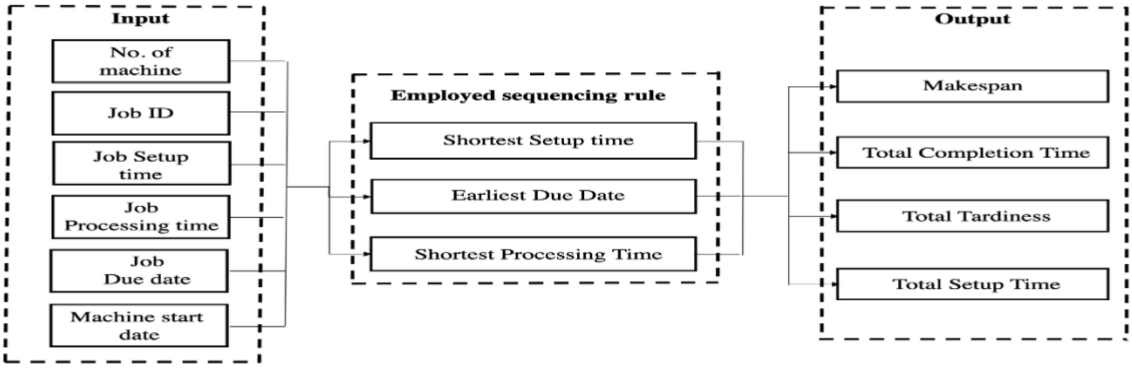

Figure 4.1 Algorithm architecture diagram

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.

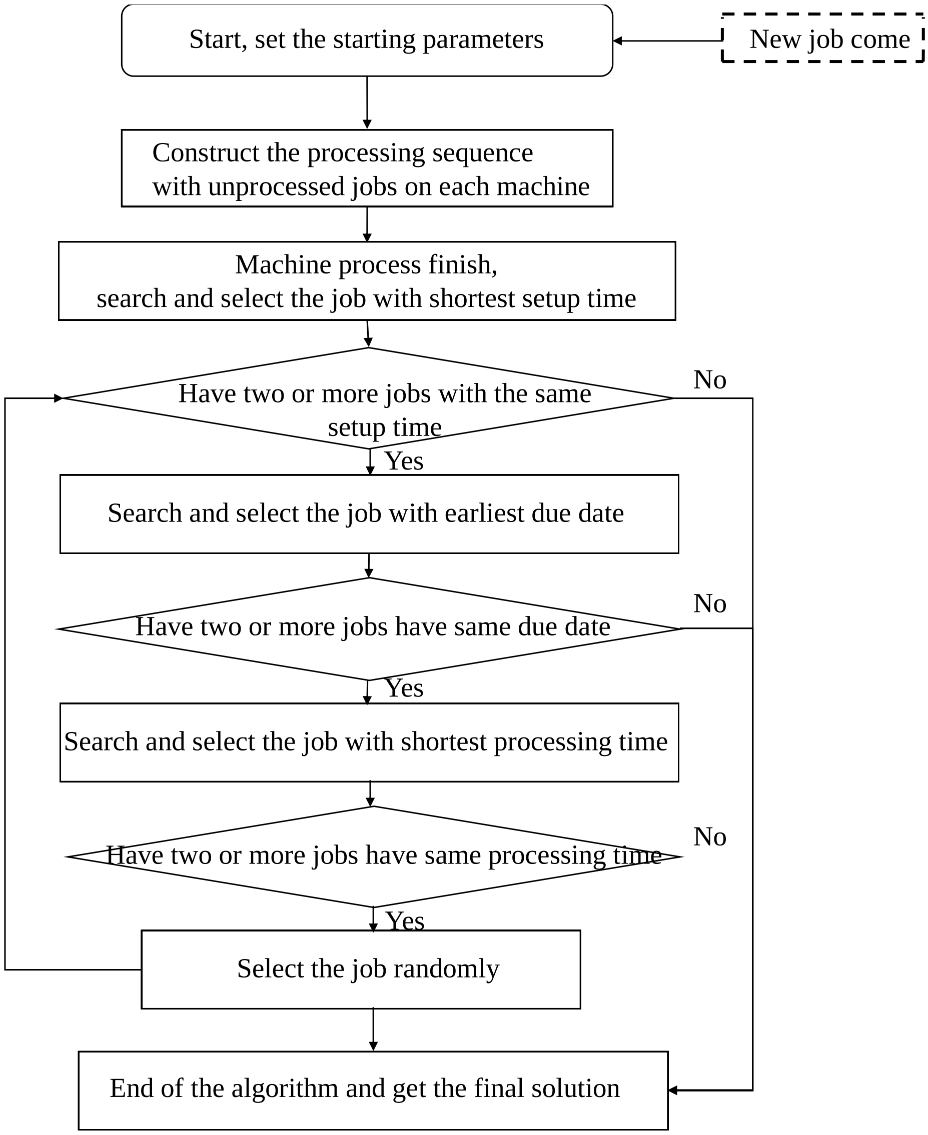

Figure 4.2 Using shortest setup time sequencing rule process

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.

4.3 Illustrative Example

Assume that there are 3 machines and 6 jobs in the system, the matrix of setup time will be created in Table 4.1, and jobs information is shown in Table 4.2.

Table 4.1 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	-

In table 4.1, the J_0 column refers to the required set up time from machine starts processing. For example, in this matrix of the third row and first column is 20, it refers to the set up time required for the machine to start processing job 2. In addition, the fourth row and fifth column in this matrix is 15, it refers to the set up time required for the machine change processing from job 3 to job 4 or job 4 to job 3.

Table 4.2 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	19-03-2019	21-03-2019	19-03-2019	20-03-2019	22-03-2019	19-03-2019

If SSUT-EDD-SPT is used, in step1 the job having shortest setup time in column J_0 of setup matrix will be selected first to assign to machine, so jobs 1,4 will be selected, and then next in step 2 jobs 2,3,5,6 will be compared based on their earlier due dates. Job 3 has smallest due date, so job 3 will be selected to assign next. The result of step1 and 2 is shown in figure 4.3.

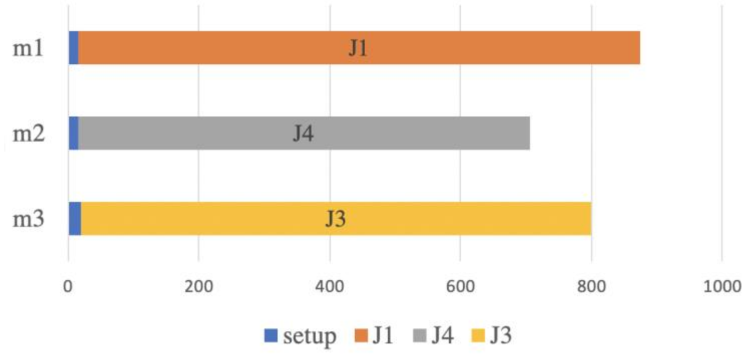

Figure 4.3 The step1 and 2 results based on SSUT rule

After, the system will allocate the job to which machine finishes first. In the example, machine 2 will finish first, so the system assigns job 2 to machine 2 because the setup time to change from job 4 to job 2 is less than the setup time to change from job 4 to job 5 or job 6. After that, machine 3 will finish first, but jobs 3, 5, 6 have the same setup time, so the system will select the earlier due date job. Therefore, job 6 will be assigned to machine 3 and job 5 will be processed on machine 1. The scheduling result of the example is shown in figure 4.4.

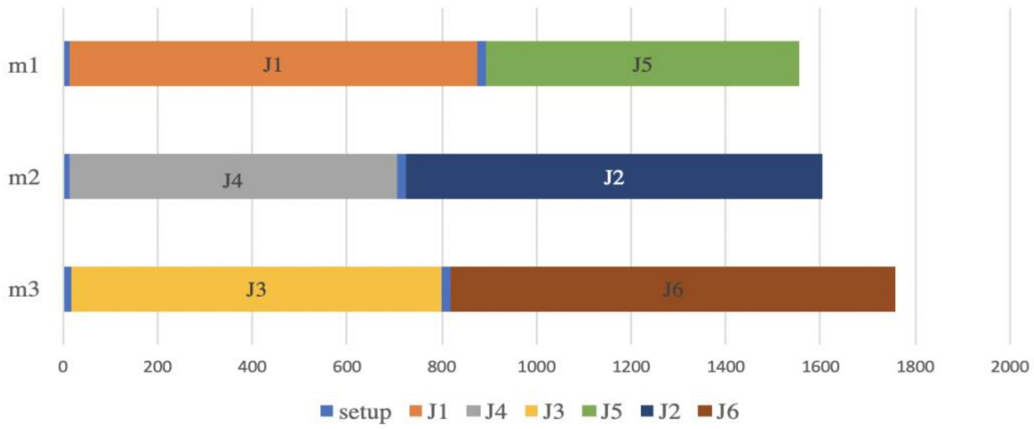

Figure 4.4 The schedule based on SSUT-EDD-SPT rule

From the above figure, the corresponding values of four criteria are as follows:

1. Makespan: 1760
2. Total completion time of each machine(min): m1:1555, m2:1605, m3:1760
3. Total tardiness(day): 0
4. Total setup time(min): 110

If EDD-SPT-SSUT is used, in step1 the job having earliest due date will be selected first to assign to machine, so jobs 3,1,6 will be selected, and then next in step 2, the system will allocate the job to which machine finishes first. In the example, machine 1 will finish first, so the system assigns job 4 to machine 1 because job 4 has earlier due date than jobs 2 and 5. After that, machine 2 will finish first, so job 2 which has earlier due date will be allocated to machine 2. Finally, the Job 5 will be assigned to machine 3. The scheduling result of the example is shown in figure 4.5.

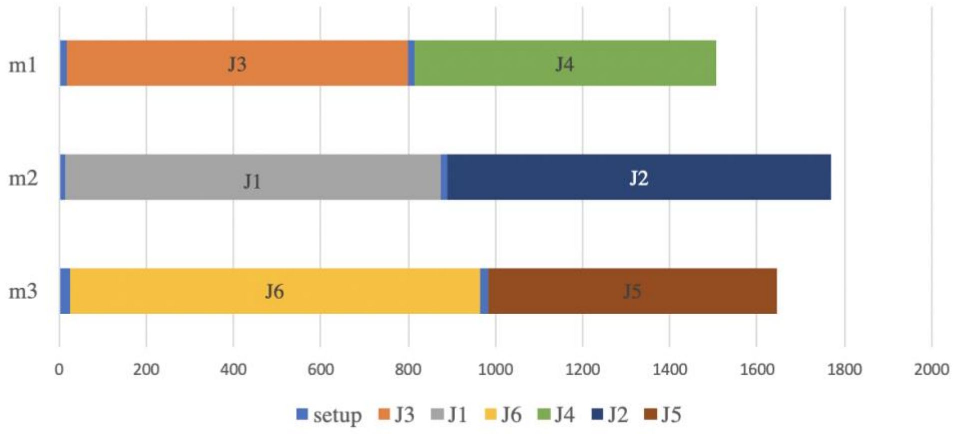

Figure 4.5 The schedule based on EDD-SPT-SSUT rule

From the above figure, the corresponding values of four criteria are as follows:

1. Make span: 1770
2. Total completion time of each machine(min): m1:1505, m2:1770, m3:1645
3. Total tardiness(day): 1
4. Total setup time(min): 110

If SPT-EDD-SSUT is used, in step1 the job having shortest processing time will be selected first to assign to machine, so jobs 5,4,3 will be selected, and then next in step 2, the system will allocate the job to which machine finishes first. In the example, machine 1 will finish first, so the system assigns job 1 to machine 1 because job 1 has shorter processing time than jobs 2 and 6. After that, machine 2 will finish first, so job 2 which has shorter processing time will be allocated to machine 2. Finally, the Job 6 will be assigned to machine 3. The scheduling result of the example is shown in figure 4.6.

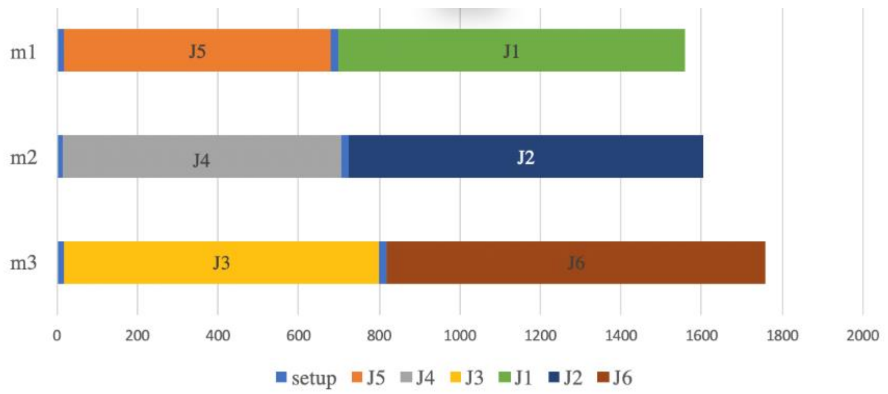

Figure 4.6 The schedule based on SPT-EDD-SSUT rule

From the above figure, the corresponding values of four criteria are as follows:

1. Make span: 1760

2. Total completion time of each machine(min): m1:1560, m2:1605, m3:1760
3. Total tardiness(day): 0
4. Total setup time(min): 115

It is noted that different combinations of sequencing rules will give the four criteria different results. The final sequence, therefore, will be decided only by production manager who has the right to make the decision. The result in the system for the model is shown in Appendix A.

4.4 Result analysis

From the results of the example, the summary is presented in table 4.3 below.

Table 4.3 The results of the example

		SSUT-EDD-SPT	EDD-SPT-SSUT	SPT-EDD-SSUT
Makespan (mins)		1760	1770	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: It is an overall time consume to complete n number of job.
2. Average flow time: A measure of the average time that a task spends in the system.

$$\text{Average flow time} = \frac{\text{Total flow time}}{\text{Number of jobs}}$$

3.Utilization: It is the optimum use of resources available like equipment, space and manpower. Maximizing the utilization of a process supports the competitive priority of cost (slack capacity).

$$\text{Utilization} = \frac{\text{Total job processing time}}{\text{Total flow time}}$$

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.

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

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

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

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

The performance measures of the example are shown in below.

Table 4.4 The makespan for each rule

Rule	Makespan (mins)	Ranking
SSUT-EDD-SPT	1760	1
EDD-SPT-SSUT	1770	3
SPT-EDD-SSUT	1760	1

In table 4.4, it shows the performance measure of makespan for each sequencing rule and the ranking. The Makespan for each rule in the example, SSUT-EDD-SPT, EDD-SPT-SSUT and SPT-EDD-SSUT are 1760, 1770,1760. For the ranking, the performance measure of makespan, SSUT-EDD-SPT and SPT-EDD-SSUT will be better choices.

Table 4.5 The average flow time for SSUT-EDD-SPT rule

	Job	Job processing time	Flow time	Job due date	Job Lateness
M1	J1	875	875	19/3	0
	J5	680	1555	22/3	0
	Sum	1555	2430		
M2	J4	750	750	20/3	0
	J2	900	1650	21/3	0
	Sum	1650	2400		
M3	J3	800	800	19/3	0
	J6	960	1760	19/3	0
	Sum	1760	2560		
Average flow time on each machine		M1	1215		
		M2	1200		
		M3	1280		
Average flow time in system		1231.67			

In table 4.5, it shows the performance measure of average flow time in the system in SSUT-EDD-SPT. First ask the flow time of each machine and then calculate the average value. In SSUT-EDD-SPT rule, the average flow time in the system is 1231.67 minutes.

Table 4.6 The average flow time for EDD-SPT-SSUT rule

	Job	Job processing time	Flow time	Job due date	Job Lateness
M1	J3	800	800	19/3	0
	J4	705	1505	20/3	0
	Sum	1505	2305		
M2	J1	875	875	19/3	0
	J2	895	1770	21/3	0
	Sum	1770	2645		
M3	J6	965	965	19/3	1
	J5	680	1645	22/3	0
	Sum	1645	2610		
Average flow time on each machine		M1	1152.5		
		M2	1322.5		
		M3	1305		
Average flow time in system		1260			

In table 4.6, it shows the performance measure of average flow time in the system in EDD-SPT-SSUT. First ask the flow time of each machine and then calculate the average value. In EDD-SPT-SSUT rule, the average flow time in the system is 1260 minutes.

Table 4.7 The average flow time for SPT-EDD-SSUT rule

	Job	Job processing time	Flow time	Job due date	Job Lateness
M1	J5	680	680	22/3	0
	J1	880	1560	19/3	0
	Sum	1560	2240		
M2	J4	705	705	20/3	0
	J2	900	1605	21/3	0
	Sum	1605	2310		
M3	J3	800	800	19/3	0
	J6	960	1760	19/3	0
	Sum	1760	2560		

Average flow time on each machine	M1	1120
	M2	1155
	M3	1280
Average flow time in system	1185	

In table 4.7, it shows the performance measure of average flow time in the system in SPT-EDD-SSUT. First ask the flow time of each machine and then calculate the average value. In SPT-EDD-SSUT rule, the average flow time in the system is 1185 minutes.

Table 4.8 The summary on the average flow time for each rule

	Rule	Mins	Ranking
Average flow time	SSUT-EDD-SPT	1231.67	2
	EDD-SPT-SSUT	1260	3
	SPT-EDD-SSUT	1185	1

In table 4.8, it shows the performance measure of average flow time in the system for each sequencing rule and the ranking.

Table 4.9 The utilization for each rule

SSUT-EDD-SPT	M1	0.639917695
	M2	0.6875
	M3	0.6875
The average utilization in the system		67%
EDD-SPT-SSUT	M1	0.652928416
	M2	0.669187146
	M3	0.630268199
The average utilization in the system		65%
SPT-EDD-SSUT	M1	0.696428571
	M2	0.694805195
	M3	0.6875
The average utilization in the system		69%

In table 4.9, it shows the performance measure of utilization for each sequencing rule. In SSUT-EDD-SPT, EDD-SPT-SSUT and SPT-EDD-SSUT rule, the average utilization in the system are 67%, 68%, 69%.

Table 4.10 The summary on the utilization for each rule

	Rule	%	Ranking
Utilization	SSUT-EDD-SPT	67	2
	EDD-SPT-SSUT	65	3
	SPT-EDD-SSUT	69	1

In table 4.10, it shows the performance measure of utilization for each sequencing rule and the ranking.

Table 4.11 The average number of jobs in the system for each rule

SSUT-EDD-SPT	M1	1.56
	M2	1.45
	M3	1.45
Average number of jobs in the system		1.49
EDD-SPT-SSUT	M1	1.53
	M2	1.49
	M3	1.59
Average number of jobs in the system		1.54
SPT-EDD-SSUT	M1	1.44
	M2	1.44
	M3	1.45
Average number of jobs in the system		1.44

In table 4.11, it shows the performance measure of the average number of jobs in the system for each sequencing rule. In SSUT-EDD-SPT, EDD-SPT-SSUT and SPT-EDD-SSUT rule, the average number of jobs in the system are 1.49, 1.54, 1.44.

Table 4.12 The summary on the average number of jobs in the system for each rule

	Rule	Jobs	Ranking
Average number of jobs in the system	SSUT-EDD-SPT	1.49	2
	EDD-SPT-SSUT	1.54	3
	SPT-EDD-SSUT	1.44	1

In table 4.12, it shows the performance measure of the average number of jobs in the system for each sequencing rule and the ranking.

Table 4.13 The average job lateness for each rule

SSUT-EDD-SPT	M1	0
	M2	0
	M3	0
Average job lateness		0
EDD-SPT-SSUT	M1	0
	M2	0
	M3	0.5
Average job lateness		0.17
SPT-EDD-SSUT	M1	0
	M2	0
	M3	0
Average job lateness		0

In table 4.13, it shows the performance measure of the average job lateness for each sequencing rule. In SSUT-EDD-SPT, EDD-SPT-SSUT and SPT-EDD-SSUT rule, the average job lateness are 0, 0.17, 0.

Table 4.14 The summary on the average job lateness for each rule

	Rule	Days	Ranking
Average job lateness	SSUT-EDD-SPT	0	1
	EDD-SPT-SSUT	0.17	3
	SPT-EDD-SSUT	0	1

In table 4.14, it shows the performance measure of the average job lateness for each sequencing rule and the ranking.

Table 4.15 The total setup time for each rule

Rule	Total setup time (mins)	Ranking
SSUT-EDD-SPT	110	1
EDD-SPT-SSUT	110	1
SPT-EDD-SSUT	115	3

In table 4.15, it shows the performance measure of the total setup time for each sequencing rule and the ranking.

Table 4.16 The summary on each 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	110
EDD	1770	1260	65	1.54	0.17	110
SPT	1760	1185	69	1.44	0	115

From the above table of performance measures, the ranking of each rule has different results. No one sequencing rule excels on all criteria. The selection of scheduling rule must be based on the performance measures which can help to achieve the maximum benefit for the company.

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.

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

In this study, two methods of SMED and scheduling are proposed to reduce setup time to solve the high-mix and low volume product demand problem for a company. SMED methodology has proven to be effective in a variety of industries. It possesses possibility of reducing setup time. This study highlights the application of SMED method in the context for molding machine where setup time drop from 1562 to 1239 seconds. Though it was observed declining of setup time decline by 20 percent, setup activities involved 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 is observed 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 changeover operations involve the steps of unlocking and locking the screws. The accuracy of the mold positioning will affect the product yield, and the simple unlocking and locking action will depend on the skill of the workers. 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 could enhance flexibility as well as efficient production 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 easier for decision makers to choose a solution that minimizes costs.

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APPENDICES

The Programming Code

In the program, at first the user should input machine and job information in order. The example shown in below figure. Machine start date:19-03-2019. In the examined company, there are two shifts per day, and working time of each day is 16 hours.

```
Enter number of machines:
3
Enter machine start date (dd-mm-yyyy):
19-03-2019
Enter number of jobs:
6
Enter setup time matrix row wise:
0 15 20 20 25 20 25
15 0 15 15 15 20 20
20 15 0 25 20 20 25
20 15 25 0 15 20 20
15 25 20 15 0 25 25
20 20 20 20 25 0 20
25 20 25 20 25 20 0
The setup time matrix is:
0 15 20 20 25 20 25
15 0 15 15 15 20 20
20 15 0 25 20 20 25
20 15 25 0 15 20 20
15 25 20 15 0 25 25
20 20 20 20 25 0 20
25 20 25 20 25 20 0
Enter job details starting from job 1 .'duration (minutes)' 'due date(dd-mm-yyyy
)' 'machine preference (-1 means any)'
Enter job details:
860
19-03-2019
-1
Job ID: 1 Duration: 860 min. Due Date: 19-3-2019 . Machine Priority: -1
Enter job details:
880
21-03-2019
-1
Job ID: 2 Duration: 880 min. Due Date: 21-3-2019 . Machine Priority: -1
Enter job details:
780
19-03-2019
-1
Job ID: 3 Duration: 780 min. Due Date: 19-3-2019 . Machine Priority: -1
Enter job details:
690
20-03-2019
-1
Job ID: 4 Duration: 690 min. Due Date: 20-3-2019 . Machine Priority: -1
Enter job details:
660
22-03-2019
-1
Job ID: 5 Duration: 660 min. Due Date: 22-3-2019 . Machine Priority: -1
Enter job details:
940
19-03-2019
-1
Job ID: 6 Duration: 940 min. Due Date: 19-3-2019 . Machine Priority: -1
```

Base on the rule of shortest set up time (SSUT), earliest due date (EDD) and shortest processing time (SPT), the system will give each criterion base on each rule. The result of the example is in below figure.

```
-----------
SSUT Result
Machine ID: 1
Jobs assigned: Job ID: 1,Job ID: 5,
Completion Time: 1555 minutes.
Machine ID: 2
Jobs assigned: Job ID: 4,Job ID: 2,
Completion Time: 1605 minutes.
Machine ID: 3
Jobs assigned: Job ID: 3,Job ID: 6,
Completion Time: 1760 minutes.

Makespan: 19-3-2019
Total Setup Time: 110
Tardiness: 0
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EDD Result
Machine ID: 1
Jobs assigned: Job ID: 3,Job ID: 4,
Completion Time: 1505 minutes.
Machine ID: 2
Jobs assigned: Job ID: 1,Job ID: 2,
Completion Time: 1770 minutes.
Machine ID: 3
Jobs assigned: Job ID: 6,Job ID: 5,
Completion Time: 1645 minutes.

Makespan: 20-3-2019
Total Setup Time: 110
Tardiness: 1
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SPT Result
Machine ID: 1
Jobs assigned: Job ID: 5,Job ID: 1,
Completion Time: 1560 minutes.
Machine ID: 2
Jobs assigned: Job ID: 4,Job ID: 2,
Completion Time: 1605 minutes.
Machine ID: 3
Jobs assigned: Job ID: 3,Job ID: 6,
Completion Time: 1760 minutes.

Makespan: 19-3-2019
Total Setup Time: 115
Tardiness: 0
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Enter number of new jobs:
```