SETUP TIME IMPROVEMENT FOR A FASTENER MANUFACTURING PROCESS

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วัตถุประสงค์ของงานวิจัยนี้คือการลดเวลาในการปรับตั้งเครื่องจักรของกระบวนการตีขึ้นรูปสำหรับบริษัทผลิตน็อตสกรู ความจำเป็นในการปรับปรุงเวลาการปรับตั้งเครื่องจักรเกิดจากปัญหาของความไม่มีประสิทธิภาพของกระบวนการตีขึ้นรูป ระยะเวลารอนานและระดับสินค้าคงคลังที่สูง ที่แสดงให้เห็นจาก Value stream mapping ของกระบวนการผลิตปัจจุบัน Cause and effect diagram ถูกนำมาใช้ในการวิเคราะห์ปัญหาของการปรับตั้งเครื่องจักร โดยหัวข้อในการปรับปรุงถูกเลือกโดยใช้ Weight score matrix

วิธีการพัฒนาแบ่งออกเป็นสามช่วง; ช่วงการวางแผน ช่วงการปรับปรุงและช่วงการดำเนินงาน ก่อนที่จะเริ่มการปรับปรุงข้อมูลที่จำเป็นของงานวิจัยนี้ได้ถูกกำหนดในช่วงการวางแผน สำหรับช่วงการปรับปรุงได้แบ่งออกเป็นสองขั้นตอน การปรับปรุงขั้นตอนแรกคือการใช้เครื่องมือ Single minute exchange of dies (SMED) โดย Shingeo Shingo สำหรับการปรับปรุงขั้นตอนที่สองได้นำ Lean tools and techniques มาใช้ในการวิเคราะห์และการปรับปรุงเวลาการปรับตั้งเครื่องจักร อันได้แก่ Pareto, Five Whys, Spaghetti diagram และ 5S system เพื่อสามารถลดเวลาการปรับตั้งเครื่องจักรให้สั้นลง ช่วงสุดท้ายคือการดำเนินการปรับปรุงอย่างเต็มรูปแบบได้ประสบความสำเร็จเป็นอย่างดี โดย Standard operating procedure (SOP) ถูกสร้างขึ้นเพื่อแสดงให้เห็นถึงวิธีการทำงานที่เป็นมาตรฐานสำหรับการปรับตั้งเครื่องจักรในอนาคต

ผลมาจากการปรับปรุงของงานวิจัยนี้แสดงให้เห็นว่าเวลาการปรับตั้งเครื่องจักรลดลงจาก 4 ชั่วโมง 9 นาที เหลือเพียง 1 ชั่วโมง 14 นาที รวมเป็นระยะเวลาที่ลดลง 2 ชั่วโมงและ 54 นาทีซึ่งคิดเป็นร้อยละ 70 นอกจากนั้นบริษัทยังได้รับประโยชน์ต่างๆจากเวลาการปรับตั้งเครื่องจักรที่ลดลง รวมถึงความสามารถในการผลิตเพียงจำนวนที่ต้องการ เพื่อที่จะหลีกเลี่ยงการผลิตที่เกินจำเป็น การลดลงของเวลารอและระดับสินค้าคงคลัง และการปรับปรุงกระบวนการผลิตให้มีความยืดหยุ่นและการตอบสนองที่รวดเร็ว

ภาควิชา	ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต	ลายมือชื่อนิสิต	....
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The objective of this research is to reduce setup time of bolt forming process in a fastener manufacturing company. The essential requirement to improve setup time arises from value stream mapping of current production process. Cause and effect diagram is used for problem analysis of setup operation. The improvement area of this research is selected by weight score matrix based on information from the analysis.

Methodology is divided into three phases; planning phase, improvement phase and implementation phase. Basis and necessary information of this research are defined in planning phase. In improvement phase, setup time improvement framework is developed consisting of two steps improvement. The first step improvement applies a well-known tool for setup time reduction, Single minute exchange of dies (SMED). For the second step improvement, lean tools and techniques are used to further analyze setup operation and improve setup time including Pareto, Five Whys, Spaghetti diagram, and 5S. Finally, full improvement implementation is successfully performed in the implementation phase.

As a result of this research’s improvement, setup time of bolt forming process is able to reduce from 4 hours and 9 minutes to 1 hour and 14 minutes. The total of 2 hours and 54 minutes is accounted for 70 percent in setup time reduction. Furthermore, the company gains various benefits including ability to produce smaller batch size in order to avoid overproduction, reduction of waiting time and inventory level, and improvement of production process flexibility and responsiveness.

Department:	Regional Centre for Manufacturing Systems Engineering	Student's Signature	....
		Advisor's Signature	....
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This research would not be possible without the fastener manufacturing company who allowed me to study, investigate, and improve the production process. A special thanks to production manager, production engineer, lead operator, and shop floor operators for their time, helpful information and great collaboration in this improvement research.

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ABBREVIATIONS

BF	Bolt forming process
FW	Finished wire
HT	Heat Treatment process
MES	Planning system interface
OEE	Overall equipment effectiveness
PK	Packaging process
PL	Plating process
QC	Quality control
SKU	Stock keeping unit
SMED	Single minute exchange of dies
ST	Sorting process
TR	Threading process
WIP	Work-in-progress
WMG	Warwick Manufacturing Group

Chapter 1: Introduction

1.1 Company Introduction

The company for this research is a Fastener Manufacturing Company established in 1974. Starting by producing self-tapping screws and machined screws, through the years, the company has expanded its product range to variety of fasteners. Currently, the company offers more than 4,700 products, including standard screws, machine screws, high tensile bolts, hexagon socket cap screws, automotive parts, motorcycle parts, and specialized made-to-order products. Examples are shown in Figure 1.

Figure 1: Sample Products

With over 4,700 products manufactured by the company, two main types of products are distinguished into standard and made-to-order types. The customers that the company serves can be divided into three main markets, that is, industrial market, export market, and aftermarket.

The company serves many industrial market segments, including automotive, motorcycle, agriculture motors, electrical, and electronic appliances. The company is also a second-tier supplier for automobile companies, such as Honda and Suzuki. Both industrial and export markets are specialized made-to-order products. On the other hand, products for aftermarket are standard made-to-stock fasteners.

The production percentage of made-to-order products continues to grow over time and gives higher revenue percentage for the company every year. The current revenue percentage of standard and made-to-order products in three customer market segments is shown in Figure 2.

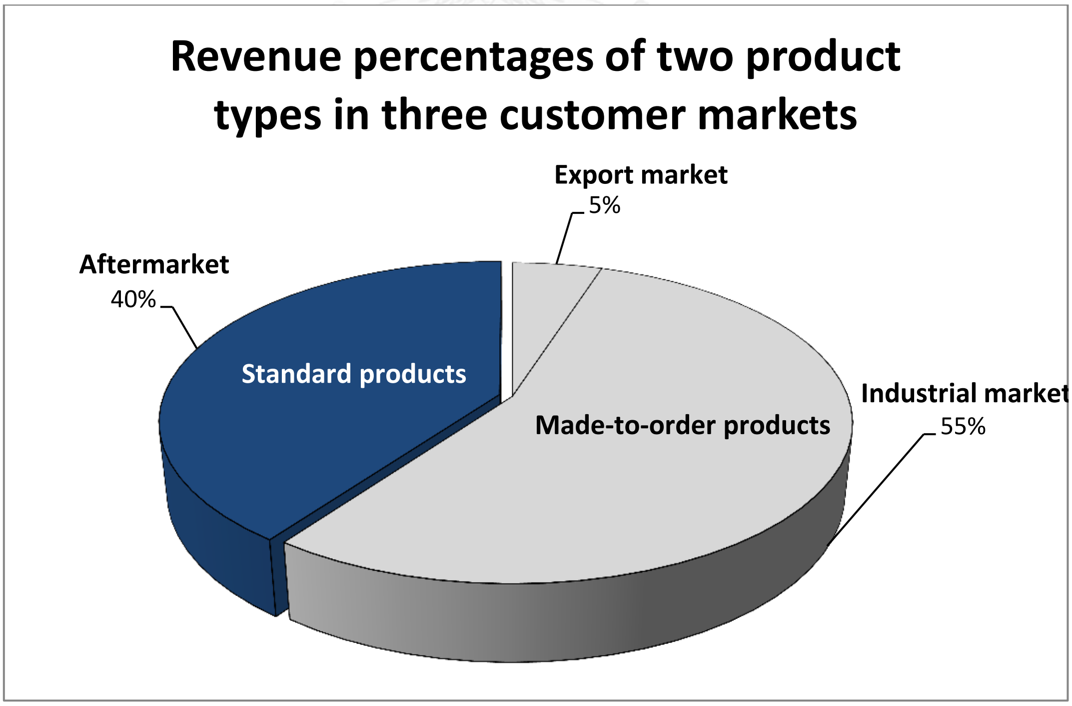

Figure 2: Revenue percentages of two main product types

(standard and made-to-order) in three markets

1.2 Company's Production Process

The company's production line consists of six main processes, that is, bolt forming (BF), threading (TR), heat treatment (HT), plating (PL), sorting (ST), and packaging (PK), as shown in Figure 3.

The company uses steel wire rod from Taiwan as raw material (RM). Since the company has a wide product range, RM has to go through several internal preparation processes, i.e. adjusting wire to the required size and right conditions. The processed wire, finished wire (FW), is then fed through bolt forming machines.

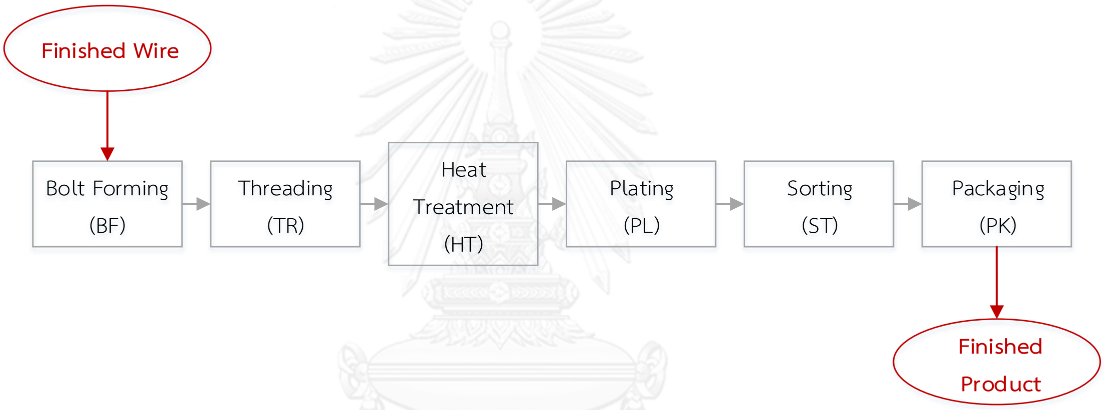

Figure 3: Production processes of the Fastener Manufacturing Company

The description of the overall production process is provided as follows;

Bolt forming process (BF)

Finished wire (FW) is fed to bolt forming machine, cut into required length, and moved through series of dies to form required shape. Bolt forming focuses on shaping head of products to the precise size, using Cold Forging method pressing finished wire at high pressure to create physical change at room temperature.

Threading process (TR)

The products from bolt forming process are then fed into a threading machine where Cold Forging method is used to create specific thread patterns on products' bodies. It is worth mentioning that both bolt forming and threading processes require machine setups.

Heat treatment process (HT)

Heat treatment process changes products' properties, using heat to strengthen, solidify internal structure, and improve brittleness of the products.

Plating process (PL)

The fourth process is plating, i.e. coating metal such as Zinc or Nickle onto products' surface. This helps protect products from oxidation and gives them various colors.

Sorting process (ST)

The company uses automatic sorting machines to check quality and dimension of the finished products.

Packaging process (PK)

In this last process, employees are involved in measuring products, either by counting or weighing products to specific amount requested by customers.

Once packed, the finished goods are ready to be delivered. However, most industrial customers prefer picking the products up at the factory on a specific date and time.

1.3 Statement of Problem

As mentioned, the company offers a wide range of products of more than 4,700 SKUs. The numbers of product variation, especially made-to-order products, also increase each year as the business continues to grow. Hence, it is necessary for the production process to be more responsive and more flexible in order to gain competitive advantage in the market and increase customer satisfaction.

As part of the continuous improvement, lean principle is applied to the company to reduce waste from the production process and the overall production time. To analyze the current production process and identify the non-value added time, Value Stream Mapping is used.

First of all, selecting a product family for the study is essential. Two main product types are identified i.e. standard and made-to-order. As shown in Figure2, made-to-order products have higher revenues of 60% than standard products of 40%. Moreover, customers are different, made-to-order products are industrial products which have higher standard on quality, delivery performance, critical to reputation and growth in the company. Hence, the product family for this study is chosen from made-to-order products.

Nevertheless, made-to-order products consist of 4 product families as shown in Table1. The same product family refers to products that go through the same overall production steps. The criteria for choosing product family for the study are based on the highest percentage of production on the shop floor, which can be inferred that it has the highest impact on production schedule and revenue of the company. According to production percentage in Table1, product family no.3 with the highest production percentage of 55.6% is selected for this study.

Table 1: Production percentage of four made-to-order product families value streams

Product Family No.	Production Process Steps	Made-to-order Production
1	FW → BF → TR → HT → PL → ST → PK → Customer	14%
2	FW → BF → HT → PL → ST → PK → Customer	21%
3	FW → BF → TR → HT → ST → PK → Customer	55.6%
4	FW → BF → HT → ST → PK → Customer	7%
5	Others	2.4%

Value stream mapping of product family no.3 is shown in Figure 4. The basis for this value stream mapping is as follows;

a) One batch of product is 2,000 kg or 35,972 pieces.

b) The working time for this company is 8 hours per day and 6 days per week.

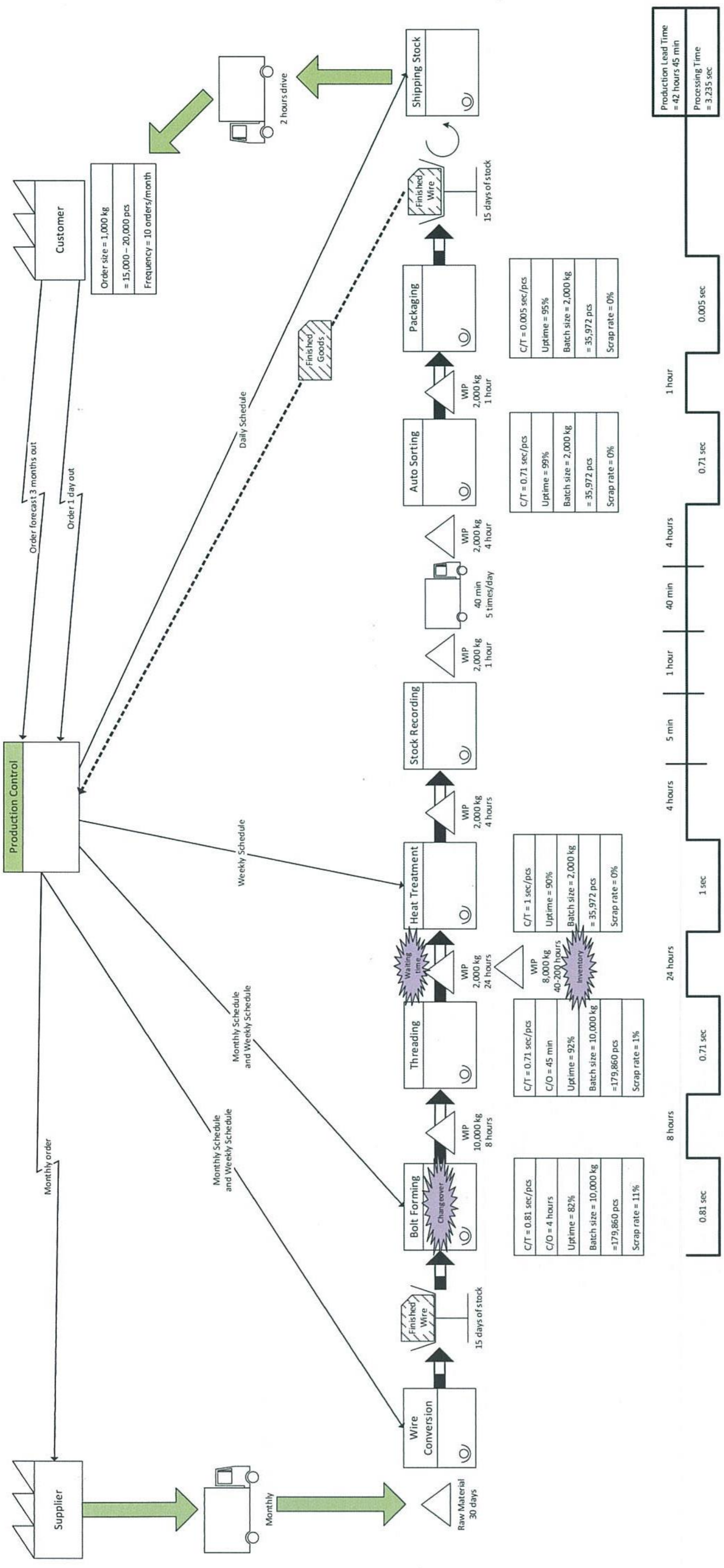

Figure 4: Value stream mapping of made-to-order fastener production process

The purpose of value stream mapping is to allow the company to see current overall production of selected product family, which helps identify wastes in the system and decides which problem to be tackled. As shown in Figure 4, there are three main problems identified that cause major concerns for the company as marked with kaizen burst in value stream mapping. Figure 5 is zoomed-in version of areas that indicate these three main problems and are described below.

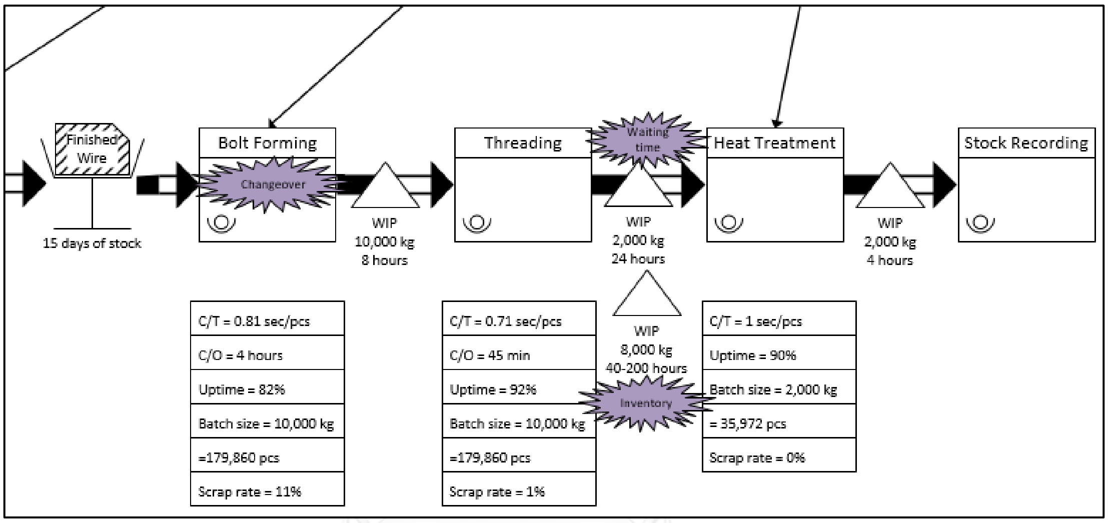

Figure 5: Kaizen burst demonstrating the three main problems in production process

1.3.1 Ineffectiveness of Bolt Forming process

Bolt forming process is necessary for all products in order to change finished wire into products with customers' requirement of shapes and dimensions. Comparing with all production processes, Bolt forming process has the lowest machine uptime percentage of 82%. Uptime percentage or overall equipment effectiveness (OEE) is calculated by the factors of availability, performance, and quality of Bolt Forming machine.

$$OEE (\%) = Availability (\%) \times Performance (\%) \times Quality (\%)$$

Availability rate;

$$a = \frac{\text{total operating time}}{\text{planned production time}}$$

Performance rate

$$p = \frac{\text{net operating time}}{\text{total operating time}}$$

Quality rate

$$q = \frac{\text{valuable operating time}}{\text{net operating time}}$$

Table 2: The initial overall equipment effectiveness

Production data	Calculation data	Calculation	Results
Shift length (per week)	8 hours per day and 6 days per week	8 x 6 hours	48 hours
Planned Production Time	8 hours per day and 6 days per week	8 x 6 hours	48 hours
Changeover Time	-	-	4 hours
Machine Downtime	-	-	0 hours
Total Operating Time	Planned Production time - Changeover Time	48 - 4 hours	44 hours
Machine Running Rate	Operating Machine Speed	-	0.81 sec/piece
Ideal Machine Running Rate	Maximum Machine Speed	-	0.81 sec/piece
Machine Speed Loss Time	Ideal Machine Running Rate - Running Rate	-	0 hours
Net Operating Time	Total Operating Time - Machine Speed Loss Time	-	44 hours

Production data	Calculation data	Calculation	Results
Scarp rate	Scrap and Non Conformance	-	11%
Quality Loss Time	Net Operating Time x Scrap Rate	44 x 11%	4.84 hours
Valuable Operating Time	Net Operating Time - Quality Loss Time	44 - 4.84 hours	39.16 hours
OEE Factor	**Calculation Data**	**Calculation**	**OEE %**
Availability (A)	Total Operating Time / Planned Production Time	44 / 48	0.92 (92%)
Performance (P)	Net Operating Time / Total Operating Time	44 / 44	1 (100%)
Quality (Q)	Valuable Operating Time/ Net Operating Time	39.16 / 44	0.89 (89%)
Overall OEE	**Availability x Performance x Quality**	**0.92 x 1 x 0.89**	**0.82 (82%)**

The overall OEE calculation indicates two inputs that reduce uptime percentage to 82%, which are changeover or setup time of 4 hours and scrap rate of 11%. As setup operation of Bolt forming machine is complicated and required trial and error adjustment to get the accurate products in all dimensions, leading to high setup time and high non-conformance products.

1.3.2. Long waiting time at Heat Treatment process

As five batches (10,000kg or 179,860 pieces) of work-in-progress (WIP) have come out of Threading process, only one batch (2,000kg or 35,972 pieces) is queued up to be processed at Heat Treatment. The other four batches are held as inventory and will be processed through Heat Treatment when Production Control requests the WIP production to replace the missing product inventory in 15-day inventory Kanban at the end of production processes once it is delivered to customer. The 15 days inventory is based on company policy as a safety stock to avoid late delivery.

Heat Treatment is considered as a bottleneck process in the system according to the highest waiting time for WIP before able to flow through this process comparing to other production processes. The one batch that is continued to queue up has the waiting time of 24 hours. Waiting time is considered as waste in the process and should be eliminated or reduced.

There are two options to improve continuous flow and reduce WIP waiting time. The first option involves high capital cost of purchasing more Heat Treatment machines in order to reduce waiting time. However, Heat Treatment machine is expensive and purchasing new machine should be considered the last option to help smoothen the WIP flow.

The second option is to produce only what is required i.e. every product every interval or to produce the smallest batch size possible. Reducing batch size allows immediate pass of WIP to Heat Treatment process and also other processes, which reduce waiting time comparing to producing big batch size as done in current situation. This involves the upstream processes of Bolt Forming and Threading to produce the smallest batch as possible to both reduce waiting time and minimize inventory between processes. However, reason that prevents the company from producing small batch size is long setup time of upstream processes especially in Bolt forming. In other words, the company is required to produce big batch of WIP to compensate the long setup times.

1.3.3 High level of inventory at Heat Treatment process

As mentioned that four batches (8,000 kg or 143,888 pieces) of WIP are stocked after Threading process and waited for production order prior to proceeding to Heat Treatment process. The approximate time of inventory is 40-200 hours.

Holding inventory creates unnecessary storage cost including money tied up which reduce cash flow in the company. It increases storage space which greatly affects the company that has many variations of products. Having inventory leads to increase in quality problems since the company's products are made of steels which can deteriorate and rust over time.

Having inventory also has its benefits, however, the amount of inventory that should be held is just enough. It is clear that four WIP batches that are waiting to be processed for 40-200 hours are much more than just enough inventories that the company should have, thus having no value to the company at that time.

High inventory problem is caused by overproduction of the upstream processes i.e. Bolt forming and Threading. Both inventory and overproduction are considered as ones of the seven wastes which should be eliminated or reduced. Hence, the upstream processes should produce only the amount that is needed at the time to reduce inventory. Again, the reason that prevents the smaller batch size production is due to long setup time in both Bolt forming and Threading processes. Hence, setup time of upstream processes especially Bolt forming should be analyzed and improved in order to reduce inventory problems.

1.3.4 Statement of problem conclusion

Three main problems that cause major concerns in the company's production processes are ineffectiveness of bolt forming process, long waiting time and high inventory level at Heat Treatment process. All three problems contain the same required improvement which is setup time and setup operation of the upstream process i.e. bolt forming and threading. Since bolt forming setup operation takes 4 hours, whereas threading takes 45 minutes, improving bolt forming setup time is the priority. Moreover, the improvement of bolt forming setup operation can later be used as prototype for other processes setup improvement.

By improving setup time of bolt forming machine, it increases uptime percentage or OEE of bolt forming machines, promotes continuous flow of WIP by reduce waiting time and finally reduces inventory at Heat Treatment process.

Furthermore, setup time reduction is always one of the aims for continuous improvement in this lean manufacturing company, to be able to change production sequence as quickly as possible due to product variation.

1.4 Research Objectives

The objective of this research is to reduce non-value added activities or waste in the production process emphasizing on bolt forming setup operation improvement and setup time reduction.

1.5 Scope of Study

The scope of this research focuses on applying lean tools and techniques on bolt forming setup operation of a fastener manufacturing company. Setup time and procedure improvement will be emphasized based on the concept of Single-Minute Exchange of Die (SMED) and other lean tools and techniques such as fishbone diagram, Pareto, and value stream mapping. Feasible framework for setup operation will be implemented in order to analyze, evaluate and compare the results before and after implementation of the improvement.

1.6 Proposed Methodology

Phase 1: Preliminary survey

- On-site inspection and operator interview
- Setup operation video recording

Phase 2: Data collection

- Review the recorded videos
- Identify all setup activities in sequence and time spent in each activity using activities log sheet.

Phase 3: Data analysis

- Analyse all associated activities and times
- Identify problems and improvement areas

Phase 4: Design new process

- Create feasibility framework to eliminate non-productive activities and simplify setup operations

Phase 5: Implementation

- Inform operators about setup operation improvements
- Implement setup operation improvements

Phase 6: Data collection and analysis

- Monitor (video recording) and record result
- Analyze and compare the result

Phase 7: Summary and suggestion

- Summarise results and benefits of the research
- Thesis completion

1.7 Research Schedule

Table 3: Research Schedule

Activity	2016																																			
	February				March				April				May				June				July				August				September				October			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Analyze and identify statement of problems	X	X	X	X	X	X	X	X																												
Theory and literature review			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Phase 1: Preliminary survey																																				
On-site inspection and interview									X	X																										
Setup operation videos capturing											X	X	X	X	X																					
Phase 2: Data collection																																				
List setup activity and time																X	X	X																		
Phase 3: Data analysis																																				
Identify problems and improvement areas																			X	X	X	X														
Phase 4: Design improvement framework																																				
Create framework and action plan																					X	X	X	X	X	X										
Phase 5: Implementation																																				
Inform operators of improvement framework																											X									
Implement the improvement framework																												X	X	X	X					
Phase 6: Data collection and analysis																																				
Monitor and record results																												X	X	X	X					
Analyse and compare results																																X	X	X		
Phase 7: Summary and suggestion																																				
Conclusion and recommendations																																			X	X
Thesis completion																																				X

1.8 Expected Benefits

The expected benefits for this study are listed below;

1.) Reduce bolt forming setup time and streamline setup operation including identify root causes of problems which has never been study before. Bolt forming process uptime percentage or OEE is expected to increase from reducing of process wastes.

2.) Allow the company to produce smaller batch beneficial from shorter setup times, leading to the reduction of waiting time and inventory between production processes.

3.) Create new feasible framework for setup operation and establish work standardization for workers to easily follow.

4.) The improvement framework for setup operation improvement can further be used for other machines in the company.

Chapter 2: Theory and Literature Review

2.1 Theory Review

2.1.1 Lean

Lean is a customer driven system approach to identify and eliminate waste. The concept of lean is to do more with less, in other words is to create more value to customer with less resources (Bhasin, 2015). Lean was first initiated by Toyota Production System (TPS) in 1980s. It consists of many tools and techniques that are widely used in many organizations and supply chains. There is no doubt that lean implementation transformation is a key to gain competitive advantages. However, the lack of good concept understanding and commitment can lead to the unsuccessful lean transformation. Finally, lean is an endless journey with philosophy of continuous learning and improvement.

Seven Wastes

Waste (muda) is referred to any non-value added activities in the process. Taiichi Ohno has defined the seven types of waste as follows;

- Overproduction

  It is considered as the most serious waste as leads to many of the problems and wastes. Overproduction is producing too much, too early or just-in-case (Bicheno and Holweg, 2008). It prevents the smooth flow of products and services which tend to inhibit quality and productivity. Overproduction causes excessive work-in-progress inventories. Moreover, it leads to excessive lead time and storage time. As a result, defects may not be detected in early stages and products may deteriorate, reflected in poor products quality.

- Waiting

  Waste from waiting is any time when goods are not moving or not having value added (Bicheno and Holweg, 2008). Waiting is directly affected the smooth of flow and the increase in production lead time.

- Transporting

  Any type of transportation is considered as waste. However, transportation is somewhat necessary and can never be fully eliminated (Bicheno and Holweg, 2008). Hence, the solution is to minimize the transportation of goods and services for example unnecessary movement or double handling should be avoided. Not only transportation is seen to be the waste of time, but it also leads to damage and deteriorate of goods being transported.

- Inappropriate processing

  This waste refers to the overly used of complex solutions to do simple tasks. For example, the usage of large complex machines instead of small flexible ones (Hines and Rich, 1997). Inappropriate processing discourages ownership and leads to overproduction to compensate large investment resulting poor shop floor layouts, extra transportation and poor communication (Bicheno and Holweg, 2008).

- Unnecessary inventory

  The waste from unnecessary inventory affects quality and productivity, results in increasing of lead time (Bicheno and Holweg, 2008). Moreover, there are hidden drawbacks causing by unnecessary inventory such as storage space requirement, money sinks and the risk of goods damage and deterioration. It is important to only have the 'just enough' amount of inventory.

- Unnecessary motions

  Unnecessary motions involve the non-ergonomic workplace or poor workplace arrangement which requires waste movement (Bicheno and Holweg, 2008). This waste is not only resulted in quality and productivity in production process, but it also leads to poor health and safety issues of employees.

- Defects

  Ohno's last waste is the waste from defects. Defects results in unnecessary cost and escalates the longer it is hidden. Therefore, preventive solutions should be implemented to prevent the production of defects in the first place, rather than finding ways to detect them. Defect is the result of the incorrect internal process such as disregard of machine maintenance and infeasible complex design of products. However, the Toyota philosophy states that defects should be regarded as opportunities to improve (Hines and Rich, 1997).

2.1.2 Value Stream Mapping

Value stream mapping (VSM) is an analyzing tool that demonstrates all actions to bring about the final products in production process, starting from raw material to the hands of customers (Abdulmalek and Rajgopal, 2007). Value Stream Mapping is known to Toyota Production System as Material and Information Flow Mapping, as it represents the flow of material and information together in one visual map (Rother and Shook, 2003). VSM allows organization to analyze the current state process to identify waste and its sources, in order to design the improved future state map.

It is believed that VSM is the starting point of any lean transformation and implementation, as it permits organization to see the overall current production flow, identify wastes and prioritize the area of improvements (Ramesh et al., 2008).

Value stream mapping can be done product family by product family. The same product family refers to the production flow that goes through the same production steps. The data is collected by walking along the production path of flows, collecting necessary data of every process (Ramesh et al., 2008). The example of value stream mapping is shown in Figure 6.

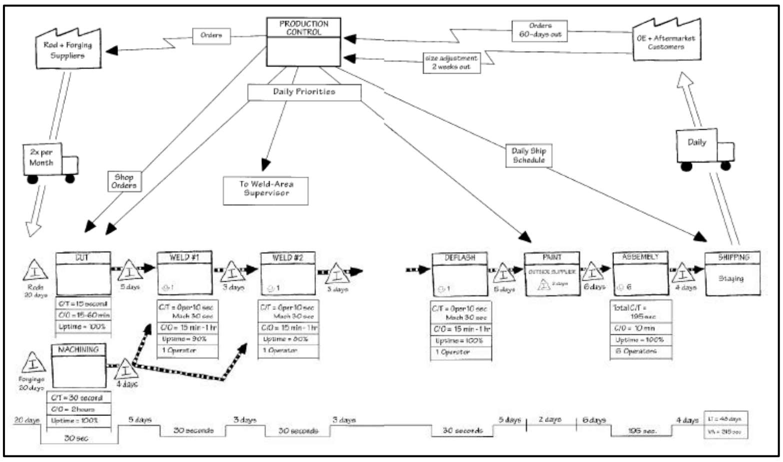

Figure 6: The example of value stream mapping

[Source: (Rother and Shook, 2003)]

2.1.3 Overall Equipment Effectiveness

Overall equipment effectiveness (OEE) is a widely used quantitative tool for equipment performance measurement. OEE analyzes three performance aspects of equipment i.e. the available time the equipment is ready to operate, the performance of the throughput rates the equipment is able to perform and the quality of the produced products (Slack et al., 2010). OEE is calculated by multiplying the factors of availability, performance, and quality.

$$OEE = Availability \times Performance \times Quality$$

This measuring tool helps identify the losses in which reduce the equipment effectiveness. The reduced effectiveness in three equipment aspects is due to the six big losses as summarized in Figure 7 (Muchiri and Pintelon, 2008). The reduction in the availability capability is caused by downtime losses from equipment breakdown or failures and setup time when the equipment is changing over from one item to another (Muchiri and Pintelon, 2008). The performance capability is reduced due to idling or minor stoppage causing from equipment temporary malfunction and due to the reduced speed of equipment when it is not running at the design capacity (Muchiri and Pintelon, 2008). And finally, the reduced in quality capability is resulted from defects or rework of the products and from reduced yield during machine start-up (Muchiri and Pintelon, 2008).

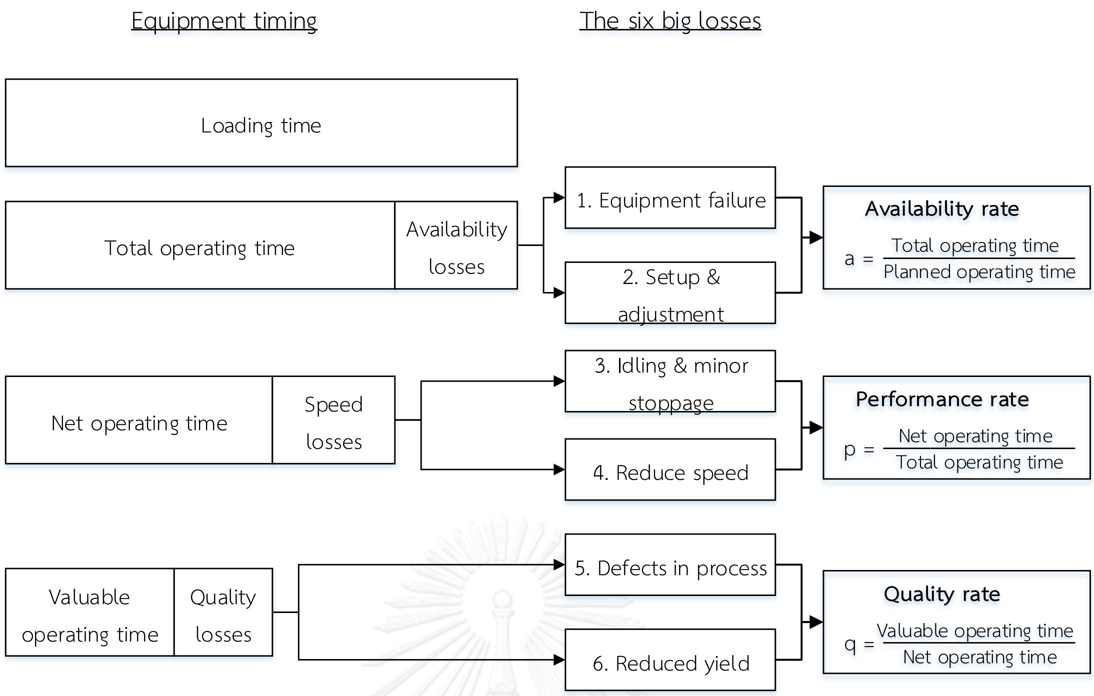

Figure 7: The overall equipment effectiveness and the six big losses

[Created by author, adapted from (Slack et al., 2010) and (Muchiri and Pintelon, 2008)]

2.1.4 Cause and Effect Diagram

Cause and effect diagram is one the lean analyzing tools that helps identify the causes of the problem. Cause and effect diagram, which is also known as Ishikawa diagram and fishbone diagram, provides the structuring group brainstorming method to identify the causes of problem (Slack et al., 2010).

It is more effective when brainstorming sessions are arrange and teams are contributing to the potential causes of problem. The commonly used of prime cause categories for manufacturing industry includes 6Ms i.e. Method, Material, Manpower, Machine, Measurement and Mother Nature (John et al., 2008). However, other problem related categories can be used as necessary.

The primary causes are normally drawn out of the central line, and then the secondary causes can be drawn out of the primary cause branch and so on. The completed diagram is seen to be like fishbone, hence the name of the diagram (Bhasin, 2015).

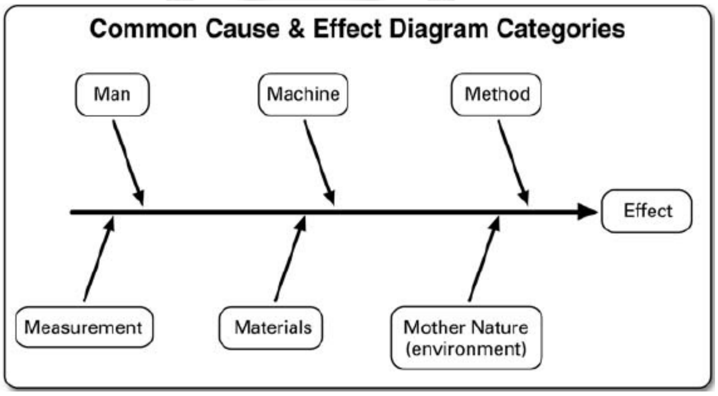

Figure 8: Example of cause and effect diagram
[Source: (Silverstein et al., 2009)]

2.1.5 Pareto Analysis

Pareto analysis demonstrates the occurrence that only few of the causes contribute to the most of the problems (WMG, 2015). This analyzing technique involves arranging contributors into orders of importance, generally measured by frequency of occurrence (Slack et al., 2010). It helps organization distinguish the few important contributors to the presented effect and select as priorities for analysis and improvement.

Pareto analysis is also known as 80/20 rule, which can be used as common phenomena, that is, the data normally presented itself in 80/20 portion (John et al., 2008). For example, majority of the problem (80 percent) is caused by only 20 percent of the contributors. As shown in Figure 9, it shows that about 80 percent of profit comes from about 20 percent of the products, this technique is also called vital few and trivial many.

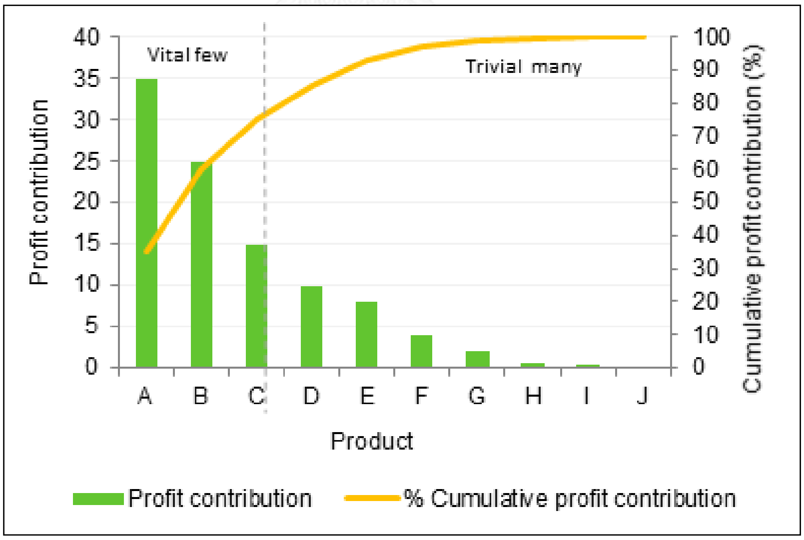

Figure 9: Example of Pareto analysis

[Source: (Sengeni, 2014)]

2.1.6 Five Whys

Five whys or Why-why is a root cause analysis technique to identify the real underlying cause of the problems. It is a simple but effective approach for systematic problem solving at the deep level causes rather than at surface level (Serrat, 2009). Five whys technique can be used in accordance with Cause and effect diagram and Pareto analysis as a practical problem solving technique.

It begins by stating the problem that needs to be analyzed, then the question "why is it happening" is asked for several times or until the root cause of problem is identified (Bicheno and Holweg, 2008). Normally, asking why for five times is the rule of thumb, however, the number of times depends on the problem being investigated.

There are some cautions when using of five whys technique. The answer to each of the question "why" must be discussed and prioritized before accepting it (Bicheno and Holweg, 2008). Moreover, it must be ensured that the answer is honest and unbiased.

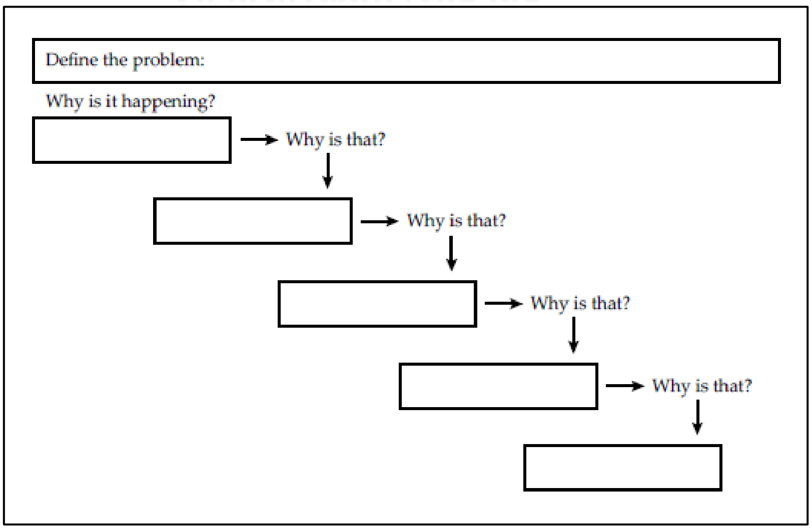

Figure 10: Example of Five Whys worksheet

[Source: (Serrat, 2009)]

2.1.7 Single Minute Exchange of Dies (SMED)

The single minute exchange of dies or SMED is one of lean tools to reduce waste causing from setup operations. It emphasizes on methodology improvement and design modification to increase the effectiveness of setup operations (Ferradás and Salonitis, 2013). SMED is aiming to improve setup time between changing over from producing one product to another, to be in a single digit number or less than ten minutes. Setup time or changeover time refers to the actual time taken to change equipment from producing the last good piece of the production lot to the first good piece of the next production lot (Coimbra, 2009).

SMED system has distinguished two kinds of setup operations, internal setup (IED, inside exchange of die) and external setup (OED, outside exchange of die). The internal setup is the operation that needed to be done only when machine is stopped. On the other hand, the external setup is the operation that can be done while the machine is running (Dillon and Shingo, 1985).

Four conceptual stages with practical techniques are offered in SMED system as shown in Figure 11 and are concluded as follows;

Stage 0: The preliminary stage

This stage is when the internal and external activities are not distinguished. It requires observing and studying the current setup operation. This can be done by various methods such as continuous production analysis (observe ongoing setup operation with stopwatch), work sampling study and videotape (Dillon and Shingo, 1985). However, the videotaping method is the most precise and highly effective, it can be watched and timed after the setup operation is finished without hustle. It is the best way to ensure that no activities are left unseen. Moreover, the video can be shown to operators for their performance review. The preliminary stage also includes interviewing the operators to define actual working conditions, problems related to setup operation and potential improvement in their point of view.

Stage 1: Separating internal and external setup

This step requires distinguishing the setup activities into internal and external setup. It is important to list all setup activities and identify the correct types of setup for each activity. The simple question can be asked “does the equipment need to be shutdown to perform this activity?” It is believed that by rearranging types of setup activities can reduce 30 – 50% of the current setup time (Cakmakci, 2009). Several practical methods for external setup are suggested in SMED system including checklist, functional checklist and transportation improvement of dies and other parts (Dillon and Shingo, 1985).

Stage 2: Converting internal setup to external setup

For setup time improvement, the remaining internal setup needs to be transferred into external setup wherever possible to reduce the overall setup time. SMED system suggested the re-examining of the possible misplaces of external setup activities in internal setup is conducted (Dillon and Shingo, 1985). Moreover, through brainstorming and exploring, the effort has to be made to convert internal setup to external setup which often includes design modification of equipment and tools. The suggested external setup practical techniques are function standardization and use of intermediate jigs.

Stage 3: Streamlining all aspects of setup operation

The final step of SMED is simplifying all setup activities including both internal and external setup. However, stage 2 and 3 can also be done simultaneously. Stage 3 requires detailed analysis of each setup activities to establish simpler ways of doing things (Dillon and Shingo, 1985). Various practical methods for internal setup have been suggested by SMED system including parallel operation, elimination of adjustment, functional clamps and mechanization (Cakmakci, 2009). The improvement of storage and transportation of dies and jigs are suggested as practical methods for external setup.

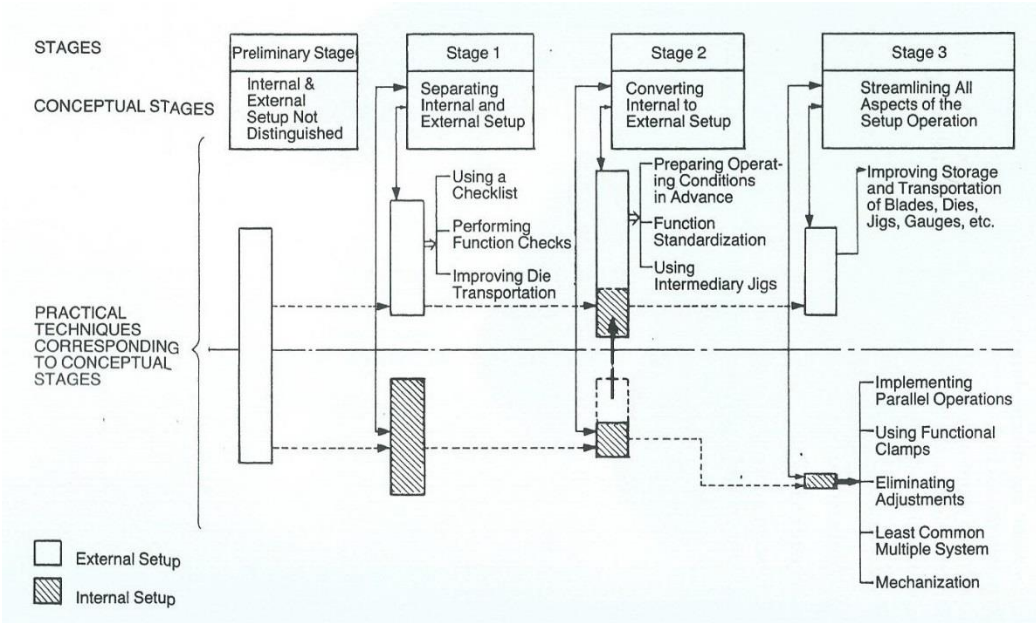

Figure 11: Single-minute exchange of die (SMED) four conceptual stages and practical techniques

[Source: (Dillon and Shingo, 1985)]

2.1.8 5S System

The purposes of 5S are to reduce waste, reduce variation, and improve productivity (Bicheno and Holweg, 2008). It is one of lean improvement tools that arranges the way organization operates as basis for process optimization (John et al., 2008). Implementing 5S can lead to the increase in operation efficiency, opportunity to recognize problems faster, and prevent injuries from operational accidents. However, this tool requires employee involvement and commitment for long term beneficial outcome.

5S is originally a Japanese terminology which can also be translated into 5S in English as follows;

Sort (Seiri)

Distinguish between what is needed and eliminate what is not needed or used. For the things that are needed, item categorization is required. Items should be marked and categorized into groups according to the set of criteria, such as area it is used or the frequency of usage.

Set in order (Seiton)

Set in order is the following step to locate every needed item in their places. It is convenient for everyone to be able to find what they are looking for, without spending unnecessary time looking for it. Moreover, it allows the misplace items to be identified easily and the use of spaghetti diagram to minimize the excess movement of employees (Bicheno and Holweg, 2008). Many techniques can be used such as shadow board and color matching of equipment to the area of usage (Slack et al., 2010).

Shine (Seiso)

Shine includes tidy up and keep the workplace clean (Slack et al., 2010). Standard routine cleaning should be developed to get all employees involved in the activities and be responsible for their workplace. The purpose of cleaning is not only for tidying up, but it also refers to checking and monitoring as well. Any abnormalities can be detected while doing cleanup, giving faster time to detect any problems and correct them (Bicheno and Holweg, 2008).

Standardize (Seiketsu)

This element includes developing a standard procedure for the first 3S as a guideline for consistent good work. A standard procedure includes sort, set in order, and shine operation that needs to be done on an organization daily basis (John et al., 2008).

Sustain (Shitsuke)

The objective of this last element is to ensure the continuity of implementation and commitment for long term improvement. 5S achievement can be made into employees' habits and embedded to organization culture. Various techniques can be carried out to sustain 5S, such as perform audits regularly (John et al., 2008). Organization can also include reward and recognition for housekeeping program to persuade employees to get involved.

2.1.9. Spaghetti Diagram

Spaghetti diagram is a visualized process mapping tool to analyze the movement in particular process. The movement categories to be studied can be employees, material, tools and information in the process (Alukal, 2007). The objective is to optimize the factory layout by reducing waste from transport and excess movement.

The first step is to draw the layout of the workplace and include all necessary details such as equipment and storage area. Observe and draw path of actual movement, use different color or symbol for different category of movement (John et al., 2008). The high precise layout and travelled distance are recommended for quantitative analysis and improvement (Bicheno and Holweg, 2008). Moreover, by drawing the moving objects such as forklift and overhead crane can be used for potential accident analysis.

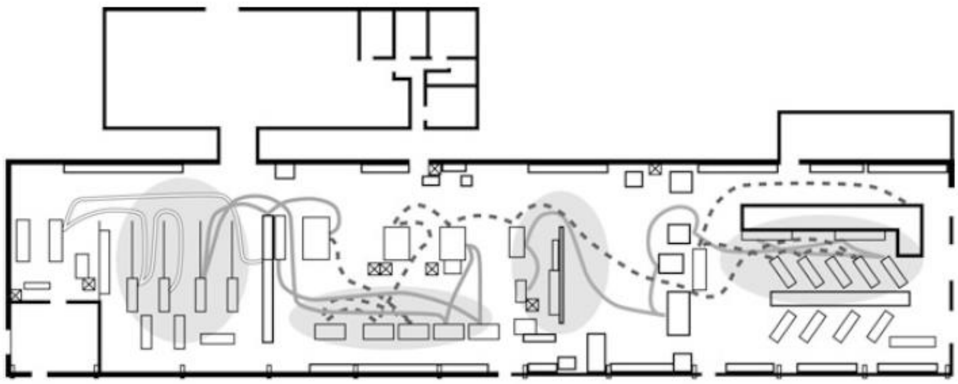

Figure 12: Example of spaghetti diagram

[Source: (John et al., 2008)]

2.2 Literature Review

As an industrial engineer consulting for Toyota Production System in 1950s, Shigeo Shingo developed scientific approach to reduce overall setup time by examining all setup operations and modifying setup process (King, 2009). This technique has become the standard of setup reduction and come to be known as Single Minute Exchange of Dies or SMED.

Setup operation is non-productive and non-value added activity, however, necessary for switching from one product to another in the production process. Therefore, it is important to minimize setup time in order to improve productivity and become more competitive in today's market. Setup time reduction is always one of the necessary features for continuous improvement program (Allahverdi and Soroush, 2008).

With various benefits that come with reducing setup time, encourage many companies to start studying and improving the current setup operation. These benefits include shorter production lead time and increase production flexibility (Berk, 2010) which leads to increase the responsiveness to high variability product demand from customer (Dave and Sohani, 2012). The reduction of setup time also allows company to produce in the optimal product batch sizes in order to lower the inventory level and achieve Just-In-Time (JIT) strategy (Yang and Deane, 1993). The optimum batch size for cost reduction can be exhibited in Economic Order Quantity or EOQ, (Carrizo Moreira and Campos Silva Pais, 2011) as a direct relationship between setup time and batch size production. Finally, the research of (Samaddar, 2001) studied the adverse effects due to setup time reduction which concluded that the reduction time caused the reduction of waiting time and WIP in the process and no adverse effects of any increasing in inventory or waiting time in the process was found.

Single minute exchange of dies or SMED system has been successfully implemented in various industries. However, SMED itself focuses on the methodology of setup operation, therefore, the application of lean tools and techniques can be found in many of the research papers as tools and techniques for maximizing the improvement including problem identification and analysis.

The researches by (Joshi and Naik, 2012) and (Deros et al., 2011) carried out the traditional SMED in automotive battery assembly line. These two case studies were similar in the ways of collecting data using stopwatch and the implementation of SMED, which divided into eight practical techniques i.e. 1) separate internal from external setup operation; 2) convert internal to external setup; 3) function standardization; 4) functional clamps; 5) intermediate jigs; 6) parallel operations; 7) adjustment elimination and 8) mechanization. (Joshi and Naik, 2012) used the average reading of the data and Pareto analysis to identify the main contributor of time loss. After SMED implementation, not only 20 percent of setup time was reduced, 30 percent cost reduction and the increased of production variety from 168 to 176 components per day were achieved. Similarly, (Deros et al., 2011) identified two bottleneck processes in setup operation that contributed to the highest time loss. The SMED approach was then applied to reduce the activities within the bottleneck processes. The result was satisfied, the setup time was reduced by 35 percent with the cost saving of RM 168,000 (Malaysian ringgit).

In 2009, quick changeovers in die-casting foundry were studied (Jit Singh and Khanduja, 2009) . The four conceptual stage of traditional SMED approach was used to eliminate unnecessary activities including study current setup operation, separate between internal and external setup, convert internal activities to external activities as much as possible, and finally simplify the all aspects of setup process. Moreover, this research used other tools and techniques to analyze the current operation and further reduce the setup times including Pareto, root-cause analysis, method study, 5S and Poke-Yoke.

Setup time reduction using SMED was studied and implemented in a Stamping Production Line in 2012 (Abraham et al., 2012). The study of current changeover procedure was done by video recording. The implementation of traditional SMED four stages was applied emphasizing on the conversion of internal to external setup, quick clamping fixture design, stamping tools standardization. In this research, many lean tools and techniques were used including Pareto analysis for bottleneck identification, 5S system for external setup improvement, and Cause-and-effect diagram and Why-why analysis for internal setup root cause identification. As results, tool change time was reduced from 7 hours to 2 hours, and the objective of productivity enhancement with minimum investment was achieved.

In a tyre manufacturing plant, SMED system was used as one of the tools to help achieve Kanban. The Kanban was the heart of achieving just-in-time (JIT) which brought many benefits to the manufacturer including inventory reduction, production planning decentralized and self-directed workforce (Mukhopadhyay* and Shanker, 2005). SMED was used along with 5S system, multi-skilling, statistical process control and visual control to achieve Kanban. The research of (Mukhopadhyay* and Shanker, 2005) applied Shingo's SMED 4 conceptual stages. The results of changing over from one component to another and same component but different sizes were 35 percent and 40 percent reduction of setup time.

The scope of SMED implementation had expanded into integration of variety tools and techniques. The improvement setup time using SMED approach together with Taguchi design of experiment (DOE) were implemented on injection molding production (Karasu et al., 2014). The SMED approach was implemented including standardized clamping and intermediary jigs for in-advance preparation of tools, multiple operators working in parallel, and elimination of adjustment by using functional clamps for quicker fastening. However, the methodology of SMED requires further improvement because the longest activity of plastic injection molding setup operation was “trial runs and adjustments”. (Karasu et al., 2014) introduced Taguchi design of experiment to identify the factors related to adjustment of this complex machine. The results shown that after implementation of only SMED, the setup time was reduced from 93 minutes to 61 minutes. Moreover, the implementation of Taguchi DOE with SMED was further reduced the setup time by another 15 minutes and number of trial-error was reduced from 26 trials to 18 trials.

Another integrated SMED implementation with design of experiments was also done on the shaping machine in automobile factory (Desai, 2012). After implemented SMED approach, the factory realized that there were further activities required to achieve setup time reduction. Further actions include house-keeping using 5S of sort, set in order, shine, standardize and sustain (Hirano, 1995) and design of experiments study to determine machine’s parameters.

As same as in Styrofoam manufacturing process (Ulutas, 2011), after applied SMED approach, the company prepared the optimal standard setup procedure for further usage. Moreover, 5S principles and Kaizen was necessary for the remaining internal process. Design of experiment was also required to determine parameters of the machine to convert changeover adjustment to setting.

The SMED system had also been used to connect with the modern technology as done in the electronics assembly factory which had complex setup procedure. It requires as much as thousands tools for setup, the modern information technology is integrated (Trovinger and Bohn, 2005). The traditional SMED was applied in the first step to identify internal and external activities in the process. The second step was developing the modern information technology system such as wireless terminals and database to assist employees on setup activities. The setup time was reduced by 85 percent.

The research of (Palanisamy and Siddiqui, 2013) was also integrated traditional SMED methodology with MES or the planning system interface. The objective was not only reduced the setup time but also scheduling setup activities in multiple machines to balance the workload, leading to increasing in machine utilization and productivity. Setup time was reduced by 69 percent. Moreover, (Palanisamy and Siddiqui, 2013) had used the Belbin roles allocation in this research which proved that the involvement of people from different department played significant roles in improving the setup operation.

One of the research conferences created the tailored SMED approach to apply on the tier 1 automotive company. (Ferradás and Salonitis, 2013) The integration of traditional SMED methodology of (Dillon and Shingo, 1985) with four stages model inspired by (McIntosh et al., 1996) of strategic, preparatory, implementation and control phases. Starting from getting management involved in strategic phase and follow by selecting project teams for the research in preparation stage. In the implementation stage, the tailored SMED was used for setup time reduction. The difference between traditional and tailored SMED was the streamlining of internal and external setup was done separately. And finally, control phase involve monitoring the improvement and sustainability. This research focused on methodology in more detailed and interested in some areas that had been neglected from Shingo methodology such as roles and responsibilities allocated to assemble a team to promote teamwork and employees involvement (Belbin, 1984).

This implementation had resulted in 33 percent setup time reduction in welding cells (Ferradás and Salonitis, 2013).

Another interesting research of SMED methodology study and implementation in medium size manufacturing plant was done by (Pellegrini et al., 2012). This research followed the scientific approach of Plan-Do-Check-Act (PDCA) cycle. Data collection was done by video filming and reviewed by the team for setup operation deeper analysis. The spaghetti chart was drawn, showing the distance of travel while doing the setup. The setup observation analysis worksheet was developed and the activities were filled in the template classifying into categories of “FAST” as defined below:

F: Foresight or the works that involved preparing for new setup operation
A: Attachment or mount/dismount tooling into/out of the machine
S: Setting or fine tuning the tooling on the machine for the new product
T: Trial runs and adjustment of tooling to fit with the product specifications

(Pellegrini et al., 2012) defined a standard operating procedure (SOP) to standardize the setup operation for sustain the effective improvement including the use of 5S for equipment storage. The unique concept of this research was the use of Idea Prioritization and Idea Assessment Matrix for the selection of improvement solution. Five criteria were set for management to considered i.e. feasibility, impact, ease of use, safety and cost. This research had reduced the setup operation from 90 minutes to 47 minutes with the further improvement suggestions.

The research of (Almomani et al., 2013) proposed the methodology to select the most appropriate setup techniques for the company by using the traditional SMED approach with multiple criteria decision making or MCDM techniques. MCDM technique has taken into account the factors that affect the decision-making process such as cost, facility layout and quality.

And finally, the study of SMED performance analysis carried out by (Cakmakci, 2009) found that, in order to achieve the optimal solution for setup operation, the solution had to be the combination of methodology improvement and design modification. The optimal solution referred to the balance between cost and time reduction. Moreover, (Cakmakci, 2009) concluded another finding that not only SMED illustrated the way of manufacturing operation improvement, but SMED could also lead to the improvement of equipment and die development.

2.3 Theory and literature review summary

According to literature review, Single minute exchange of dies (SMED) methodology had been implemented in various types of industries. Since the setup machine was different for every company, each of the implementation was based on the traditional SMED proposed by Shingo, however, adapted and brought about the suitable tools and techniques to fit with specific requirements and limitations.

The reviewed researches showed promising results to successfully reduce the setup time. Many methods were integrated with traditional SMED to further improve the results. Those methods mentioned in literature review included design of experiment (DOE), information technology system, related department in organization involvement, tailored framework, and lean tools and techniques such as 5S system, Pareto, and why-why analysis.

As the result, the author decided to develop an improvement framework using traditional SMED system and bring many useful methods into this research in order to maximize the improvement result. The improvement framework has to be adapted to best suit with the circumstances for the company in study.

Chapter 3: Process description and problem analysis

This chapter provides necessary information for bolt forming setup time improvement, including the overview of bolt forming setup operation and internal department responsibilities related to bolt forming process. Furthermore, problem analysis is performed to find causes of long setup time. And finally, improvement area is selected as improvement scope for this research.

3.1 Bolt Former Overview

Bolt forming is the first production process for all fastener products in the company. Bolt former is a four-step transformation machine that transforms raw material (finished wire) into the required products of various shapes using cold forging method. The front view of bolt former is shown in Figure 13.

Bolt former is a complex machine and considered the most difficult machine for operator to setup. The company owns 24 bolt formers at the moment. The machine uses high horse power to form product by cold forging at room temperature and can produce up to 120 screws per minute at maximum speed (0.5 sec/screw).

Due to the complication of setup operation, it has been challenging to study and touch upon the improvement alternatives. It requires good understanding of all parts that are input into the machine and how it comes to operation.

Figure 13: Bolt former (BF 23)

3.1.1 Bolt former configuration

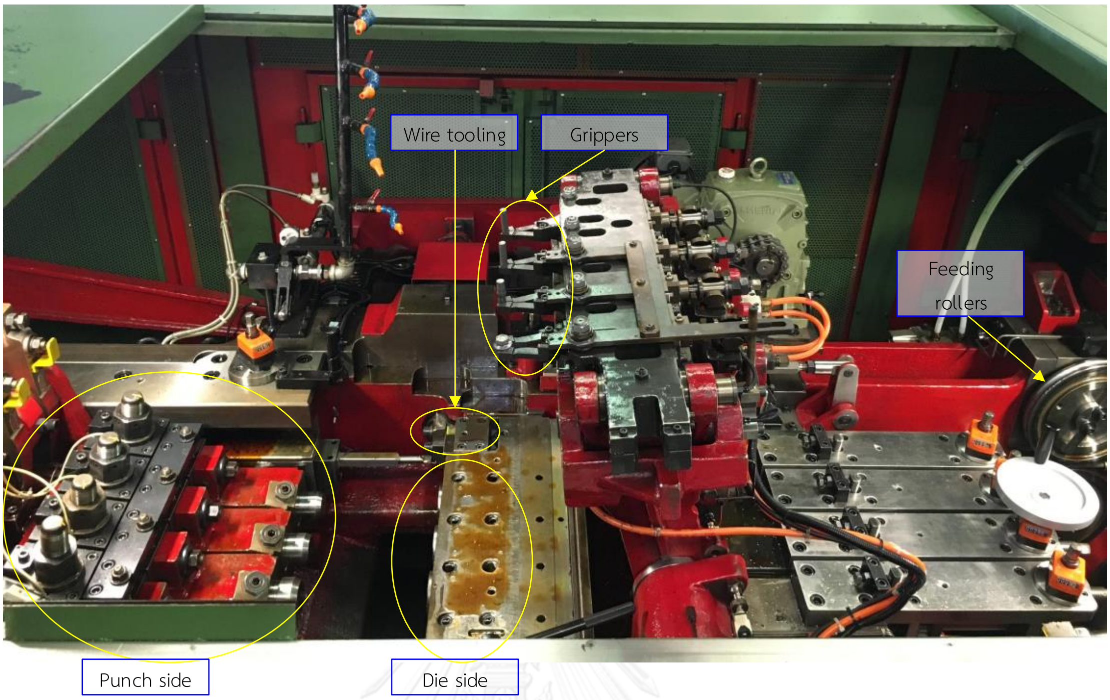

Figure 14: Bolt former inside configuration

The important features inside the machine are shown in Figure 14. During machine operation, finished wire rod at the front of the machine is fed through feeding rollers in order to smooth the wire before being cut into required length by wire toolings. The cut wire is physically shaped to the required product by passing through series of dies and punches, using grippers to catch the product from previous step to the next. The punch side is the side to move toward the die side to form the required shapes of the products such as the head of the bolts. While grippers move from right to left to deliver the shaped product from previous step to be shaped in the next step. And finally, products from the fourth step fall down to the receiving tray and out on the output tray in front of the machine.

3.1.2 Bolt former adjustment and lock parts

Adjustment is a necessary activity during botl forming setup operation in order to produce the products with accurate size and dimension. The detail of adjustments and locks perform in regular bolt forming setup operation are shown in Figure 15 and the descriptions are explained in Table 4.

The adjustment parts consist of reading scales and bolts which can be adjusted by hands or wrenches depending on the configurations. On the other hand, tighten and loosen parts are performed by different type of wrenches. Before making any adjustment, the adjustment lock must be loosen. After finish with adjustment, the adjustment lock must be tighten to be ready for high horsepower operation.

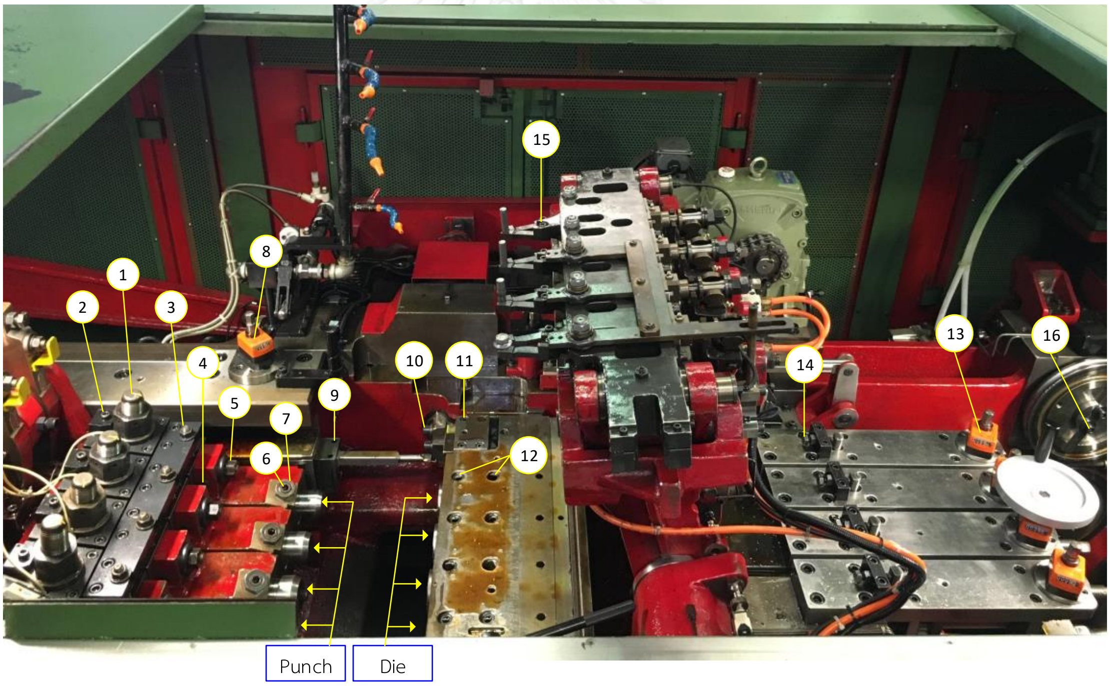

Figure 15: Adjustments and locks parts use during bolt forming setup operation

Table 4: Detail of adjustments and locks during bolt forming setup operation

Number	Category	Function	Description	Remark
1	Punch	Adjustment	Forward/backward adjustment	Note 1
2	Punch	Lock	Forward/backward adjustment lock	Note 1
3	Punch	Adjustment	Upper/lower adjustment	Note 1
4	Punch	Adjustment	Left/right adjustment	Note 1
5	Punch	Lock	Upper/lower and left/right adjustment l	Note 1
6	Punch	Lock	Punch position lock (double lock)	Note 1
7	Punch	Lock	Punch position lock (double lock)	Note 1
8	Wire	Adjustment	Wire length adjustment	-
9	Wire	Lock	Wire length adjustment lock	-
10	Wire	Lock	Wire toolings position lock	-
11	Wire	Lock	Wire toolings position lock	-
12	Die	Lock	Die position lock	Note 1
13	Die	Adjustment	Forward/backward adjustment	Note 1
14	Die	Lock	Forward/backward adjustment lock	Note 1
15	Gripper	Lock	Grippers position lock (adjust manually and tighten lock)	Note 1
16	Feeding roller	Lock	Feeding roller position lock	Note 1

Note 1: Details are common to all four steps.

3.1.3 Bolt former input components

In order to perform changeover from producing one product model to another, bolt former requires three changeable inputs.

1.) Finished wire

Figure 16: Steel wire rod (finished wire) as raw material for bolt forming process

2.) Toolings

Toolings are manufacturing components required for machine inputs in order to create essential outcome. The toolings required by bolt former are dies, punches, wire tooling, and grippers as shown in Figure 17.

Figure 17: Toolings for bolt forming setup operation

(Right front row: 4 sets of grippers, Left front row: 2 pieces of wire tooling,

Second row: 4 sets of punches for 4 steps transformation,

Third row: 4 sets of dies for 4 steps transformation)

3.) Feeding roller

Feeding rollers set as shown in Figure 18, are located beside every bolt former machine in all required sizes for different sizes of finished wire.

Figure 18: Feeding rollers for bolt forming process

3.1.4 Bolt former products

The products cannot be made in one step due to the limited physical properties of steel and the complexity of products. The four step transformation allows steel to slightly change physically as the product goes through each step and finally gets the finished product at the end of the fourth transformation step.

Even though standard bolts and screws only require two or three steps transformation, most of made-to-order products require all four steps transformation due to its high complexity. The example of product at each step of transformation through bolt former is shown in Figure 19.

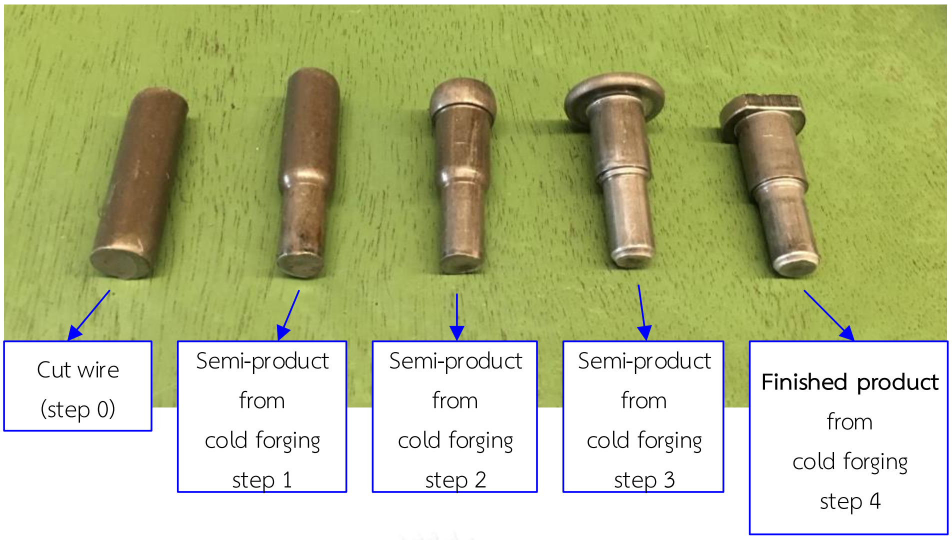

Figure 19: Example of four step transformation product

Measuring tools

Vernier caliper and micrometer are used to measure size of each part of the finished products to match with the values specify in Production order such as the length of screw and thickness of screw's head.

Figure 20: Measuring tools: Micrometer (left) and Vernier Caliper (right)

3.2 Bolt forming setup operation and related internal department

It is necessary to understand the work flow in the factory to further identify factors affecting bolt forming setup operation, which can lead to improvement alternatives. There are four departments on factory side of the company that have responsibilities and areas related to bolt forming setup operation i.e. Engineering, Planning, Production and Quality Control department. Details of each department's responsibilities are explained in section 3.2.1 to 3.2.4. Figure 21 shows the organization chart of the studied company, with summary of internal departments and their bolt forming setup operation related works.

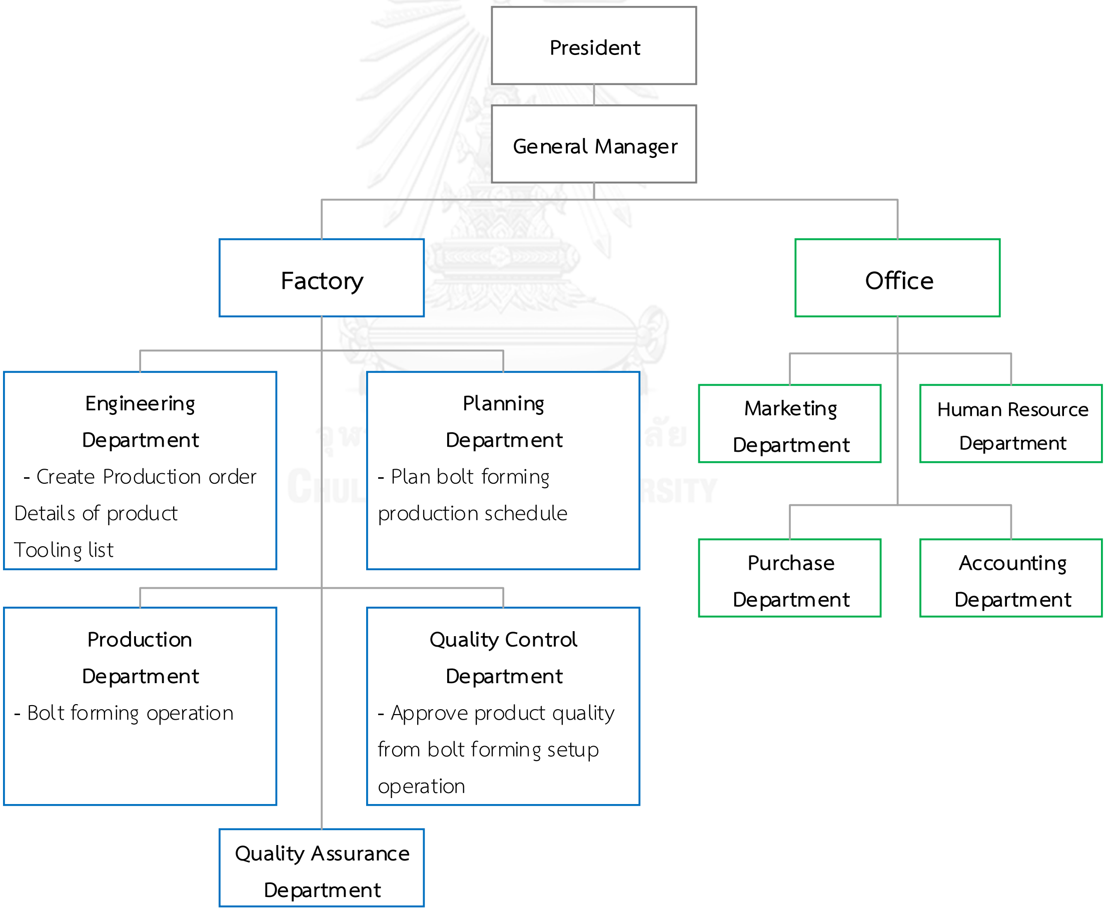

Figure 21: Organization chart with summarized bolt forming related department

3.2.1 Engineering Department

Engineering department is responsible for drawing and designing of new product models including the list of required toolings for bolt forming setup operation. Moreover, Engineering department creates Production order for each product for the production, which is the guideline for the bolt forming setup operation.

The Production order consists of product detail and information such as production work order, production amount, product appearance and dimension. Example of product A's Production order is shown in Appendix A.

3.2.2 Planning Department

The Planning department is responsible for arranging master production schedule for the factory. For bolt forming operation, Planning department plans the production schedule and assigns the production to each bolt forming machine. The schedule is made by estimating production time, based on the product amount and setup time.

Moreover, planner has to plan the same size product to be produced next to one another in production scheduling. Since the required finished wire (raw material) is the same size, the next setup operation can be reduced.

3.2.3 Production Department

The Production department is responsible for all production processes in the factory. The responsibilities include producing the products to the schedule and resolve all problems face on the shop floor. For bolt forming setup operation, the necessary detail of products is given in Production order and the production schedule is given by master production schedule.

3.2.4 Quality Control Department

Quality control department is responsible for the product quality in each production process. This includes shop floor investigation, lab testing, and calibration of measuring tools. Quality control personnel are also the ones who approve quality of the first piece product from bolt forming setup operation. Once the quality is approved, operator can start the production.

3.3 Problem Identification and Analysis

As mentioned that bolt former is a complicated machine, various causes are contributed to long setup time. In order to identify the causes of this problem, an internal meeting was arranged with the participants associated with bolt forming process comprising of production manager, production engineer, and lead setup operator. The objective of the meeting was to brainstorm the possible causes for long setup time using cause and effect diagram as analyzing tool.

Seven prime cause categories (7Ms) were identified, using (John et al., 2008) as the basis, i.e. Method, Material, Manpower, Machine, Measurement, Management and Mother Nature. The details for each primary cause were discussed and analyzed in the meeting. The results are shown in Figure 22.

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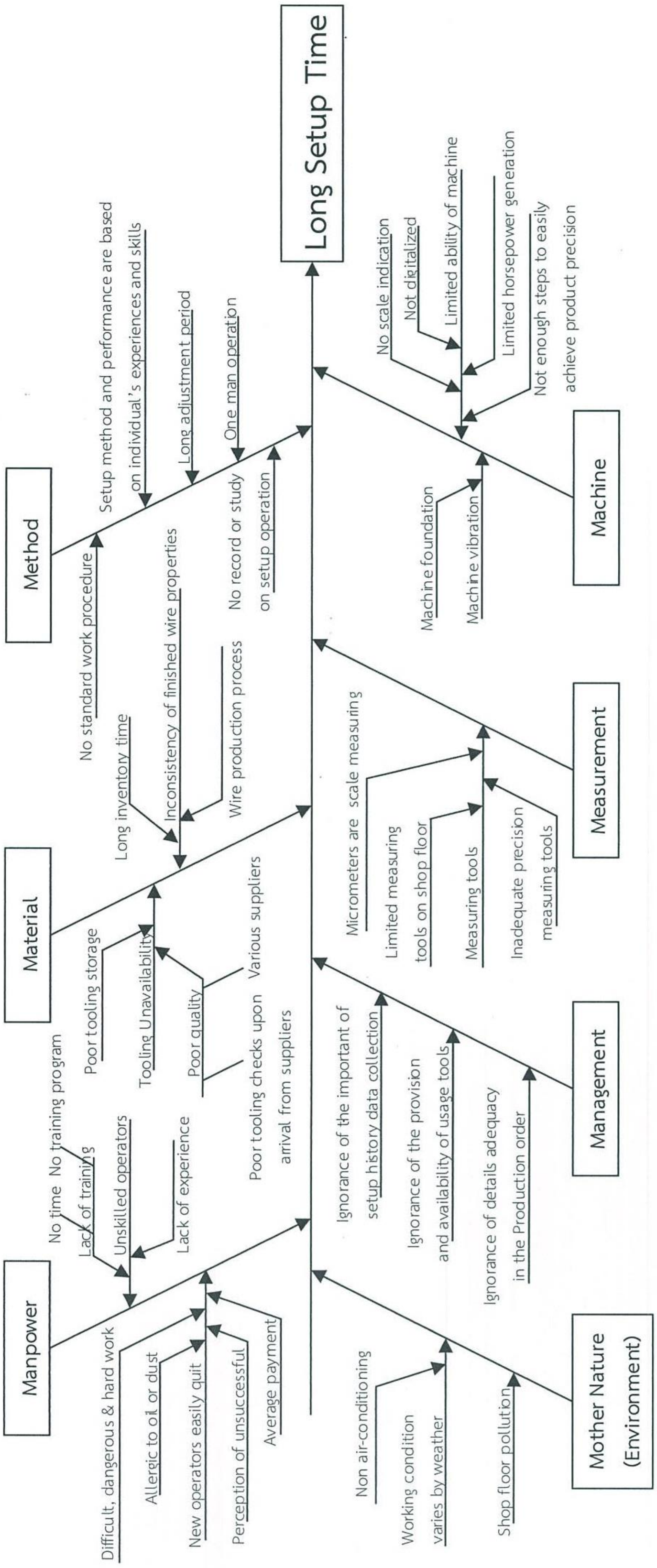


Figure 22: Cause and effect diagram for long setup time

The cause and effect diagram covers all aspects of bolt forming long setup time. The next step is to analyze the possibility of improvements for each primary cause by considering constraint and limitation of the company.

3.3.1 Method

The problem associates with method or methodology of setup operation is that there is no standard operating procedure (SOP) for such an operation. The methodology of bolt forming setup operation has never been studied before. The setup method depends on operator's skill and experience. One operator is responsible for completing setup operation with some helps from lead operator, if necessary. This leads to inconsistent setup performance and time, resulting in inaccurate planning and delays of production process. The company believes that the bolt forming setup method is the major cause of long setup time and requires immediate improvement.

3.3.2 Material

Material of bolt formers are divided into two inputs i.e. finished wire and toolings.

Finished wire

The inconsistency of finished wire properties is the primary cause of long setup time. After receiving raw wire from suppliers, finished wire is being prepared by company's internal process. Wire preparation processes are cleaning, baking, and pressing which are the sources of inconsistent properties. For example, too much wire hardness can cause breakage of toolings and too low hardness can cause setup difficulty in producing product with accurate dimension and sharpness. Moreover, finished wire is often stored in the factory for a long time before being used in production process which leads to wire quality issues such as rust and deterioration.

Toolings

Toolings are essential inputs to create the specific product. The unavailability of any tooling prolongs setup operation and interrupts continuity of production. Tooling unavailability is caused by poor tooling storage which makes it difficult to locate the specific tooling, and poor quality of tooling from suppliers. Since the company uses many suppliers to save money and time, tooling qualities are varied and inconsistent. The company stores the received toolings in tooling store and neglects to check for quality upon tooling deliveries. Poor quality toolings are then being detected during the setup operation which either requires new order from supplier or tooling modification by setup operators.

3.3.3 Manpower

Unskilled operators is one of the causes of long setup time in manpower category. Since the company does not provide standard operating procedure or proper training, new operators only gain experience through on-the-job training on shop floor under supervision of lead operator. The lead operator said that operators must have at least 2 years of setup experience in order to perform setup operation from start to finish by themselves.

Another related cause is new operators easily quit which also leads to frequently unskilled operators. Due to the nature of work that are difficult and dangerous from operating heavy machines, new operators often have perceptions of being unsuccessful, together with only average payment, they choose to leave the company to seek for the easier job with the comparable payment.

3.3.4 Machine

The company owns total of 24 bolt former machines. All machines are standard bolt former models which available in the market. At the current state, company prefers not to purchase new machine since the models are similar to the ones the company possess, which would not help with setup time reduction. Therefore, all mentioned limitations in cause and effect diagram (Figure 22) are unavoidable. However, the company can either send recommendations to supplier on machine modification or decide to modify the machine to reduce setup time.

3.3.5 Measurement

The measuring tools using in bolt forming setup operation are Vernier caliper and Micrometer, to measure the finished product to the required dimensions. Vernier calipers are digital but micrometers are still scale measuring which takes longer time than the digital measuring tools and can easily cause reading error. Furthermore, there are limited number of measuring tools available on the shop floor resulting from misplacing and disappearing which are believed to be stolen.

3.3.6 Management

Management team is unaware of the importance of quick changeover, hence, no attempt was made to reduce machine setup time. Not only the setup performance was never been measured but also the information for setup guidance was never been in the company’s action plans. Setup guidance such as historical product data and the complete list of required toolings in Production order, are the information that help operators setup the machine faster.

3.3.7 Mother Nature

Mother nature is the environment around working area which is the open air on the shop floor. Even though working conditions such as hot climates and pollution from manufacturing process can affect the setup performance, bolt former are not to be relocated to air-conditioning room due to high operating cost and unnecessity.

3.4 Improvement Selection

After analyzed details in each cause of long setup time, three cause categories were considered and identified as potential major impacts on setup time reduction i.e. method, material, and manpower. Moreover, these three causes had defined scope for this research and big enough to be an improvement project for the company.

However, with limited time frame, this research focused on one of the problems to improve as the priority. In order to decide which of the improvement areas should be selected, the weighted score matrix was used to evaluate these three improvement alternatives. The weighted score matrix was adapted from the supplier selection approach (Slack et al., 2010). The production manager was the person who assigned weights and scores to each of the criteria and improvement alternatives, to reflect the strategy for this research.

The first step was to setup the criteria, which represented concern aspects of this research. Six criteria were set in accordance with the preferences and constraints of the company:

1.) Results on Setup Improvement and Setup Time Reduction

2.) Achievable in limited time frame

3.) Create long term solution

4.) Positive Effect on Customer Perspective

5.) Financial Investment

6.) Product Quality

The criteria was then scored (weight from 1 to 5) on the importance of each criteria to the company. The meaning of each weight is shown in Table 5.

Table 5: The relationship between weight and level of importance

Weight	Importance of the criteria to the improvement areas (method, material and manpower)
5	Extremely important
4	Very important
3	Considerable Important
2	Less important
1	Not important

The next step was to assign scores on to all three improvement alternatives and six criteria. Scoring was categorized into in scale of 1 to 5. The implications of the scores for six criteria are explained in Table 6.

Table 6: Scoring details for weight score matrix

Criteria	Score				
	5	4	3	2	1
1.) Results on Setup Improvement and Setup Time Reduction	Significantly Exceed Expectation: Potential setup time reduction to be within 10 minutes.	Exceed Expectation: Potential setup time reduction to be within 1 hour.	Meet Expectation: Potential setup time reduction to be within 2 hours.	Below Expectation: Potential setup time reduction to be within 3 hours.	Significantly Below Expectation: Potential setup time reduction to be between 3 to 4 hours.
2.) Achievable in limited time frame	Achievable within 3 months.	Achievable within 3-6 months.	Achievable within 6-9 months.	Achievable within 1 year.	Achievable in more than 1 year.
3.) Create long term solution	Create solution for more than 10 years.	Create solution for more than 5 years.	Create solution for more than 2 years.	Create solution for more than 1 year.	Do not create long term solution.
4.) Positive Effect on Customer Perspective	Significantly improve company's image perceived by customers.	Highly improve company's image perceived by customers.	Considerable improve company's image perceived by customers.	Slightly improve company's image perceived by customers.	Do not improve company's image perceived by customers.
5.) Financial Investment	Not require any investment from the company.	Require 1-5,000 baht from the company.	Require 5,000-10,000 baht from the company.	Require 10,000-100,000 baht from the company.	Require more than 100,000 baht from the company.
6.) Product Quality	Significantly effect on quality of output products.	Highly effect on quality of output products.	Considerable effect on quality of output products.	Slightly effect on quality of output products.	No effect on quality of output products.

After production manager assigned all weights and scores on the matrix. Total score for each of the three improvement alternatives were sum up using equation below:

Total score of each improvement alternative = ∑ (weight x score)

Table 7: Weight score matrix for improvement selection

Decision Criteria	weight	Score		
		Method	Material	Manpower
1.) Results on Setup Improvement and Setup Time Reduction	5	3	2	2
2.) Achievable in limited time frame	3	4	2	4
3.) Create long term solution	5	5	5	5
4.) Positive Effect on Customer Perspective	3	5	3	3
5.) Financial Investment	2	5	3	5
6.) Product Quality	5	5	5	2
Total score		**102**	**81**	**76**

In Table 7, the result shows that Method has the highest score of 102 which made it the improvement priority for bolt forming setup operation and became the improvement area for this research. The company believed that by improving method of setup operation, setup time would meet company's expectation of within 2 hours in 3 - 6 months' time frame. From the current point of view, it can create long term solution for more than 10 years for bolt forming process. Furthermore, this research was also expected to significantly improve product quality and customers' perspective of the company with no investment required.

Even though Method was selected to be the main focus of this research on bolt forming setup time improvement, other improvement alternatives were closely related and were considered for potential improvement as well.

3.5 Process description and problem analysis summary

Necessary information about bolt former and bolt forming setup operation were described in the beginning of this chapter. Moreover, internal departments' works and responsibilities that related to setup operation were also discussed. This covered all factors that other departments contribute to bolt forming setup operation for potential coordination solutions and improvements.

Cause and effect diagram was used to analyze causes of bolt former long setup time. In order to cover all aspects of the problem, seven causes were discussed including method, material, manpower, machine, measurement, management, and mother nature. After detailed analysis and potential solution consideration, three potential improvement projects were interested.

Weight score matrix was then used to select the improvement area. Both weights for decision criteria and scores for each improvement alternatives were assigned by Production manager based on practical and limitation of setup operation. As a result, **Method** of bolt forming setup operation was selected to be the improvement area for this research.

Chapter 4: Methodology

This chapter proposes methodology for setup operation method improvement base on the reviewed of academic theories and setup time reduction related literatures. As inspired by research methodology of (Ferradás and Salonitis, 2013), author has divided this research into 3 phases; planning, improvement and implementation phase, which are proceeded in sequence.

4.1 Planning phase

Planning phase defines the necessary information of this research before going forward. It clarifies the objectives of this research, those who involve, research's limitations and time frame. Therefore, planning phase consists of defining scope of research, forming a team, defining all constraints, and specifying deadline.

4.1.1 Define scope of research

- This research focuses on bolt forming setup operation improvement to reduce setup time to be within 2 hours.
- The bolt former machine number 23 (BF 23) is used for this research. BF23 machine is a standard model of bolt former used on the shop floor. Other bolt formers are able to apply the same improvement procedures once BF23 is successfully improved.
- Product model A is selected to be studied in this research. Product A is a made-to-order product in product family no.3, which represents the highest production in the company. Furthermore, the production of product A requires 4 steps transformation of bolt former, representing the most complex type of products within this company and also the longest time to do setup operation.
- Data collection is done by video recording the setup operation. Due to time limitation and data accuracy, data is collected 3 times in both current and improved setup operations. In case there is no significant difference in the collecting data, the longest time among the three is selected to represent the worst case scenario of setup operation.
- This research emphasizes on the use of Lean tools and techniques for the improvement.

4.1.2 Form a research team

Not only this research requires company's commitment and collaboration from start to finish, but it also requires authorization and expertise in specific area to facilitate analysis and improvement. Therefore, research's team members are selected according to their functionalities, consisting of production manager, production engineer, lead operator, and setup operator. All team members are responsible for disclosing necessary information and brainstorming for potential improvement in a fair tendency to prevent an unbiased study and result.

- Production Manager

  Production manager is able to make decisions and approve details regarding the research, including plans and implementations.
- Production Engineer

  Production engineer supervises the overall implementation and procedure of this research on the shop floor. He also helps coordinate between related parties about the improvement concept and information as necessary.
- Lead operator

  Lead operator is an important consultant for this research. He supervises all operations in bolt forming process for more than 15 years. Therefore, he has the most experience and knowledge about the process including bolt forming setup operation, limitation of the operation, and other practical issues that has never been on company's records.
- Operator

  A setup operator is selected as one of team members as he works on bolt forming setup operation on daily basis. He is able to identify the problems of setup operation on the shop floor. Moreover, this research observes and studies bolt forming setup operation through this operator.

4.1.3 Define research constraints

Constraints of the setup improvement must be stated to allow improvement to be realistic and suitable for every day's operation on shop floor.

Company side

- The company expects small or no investment for this research.
- The company is not allowed the modification of bolt former machine without approval from machine maker due to safety concerns.
- The study and implementation has small or no effects on production schedule.

Setup operation side

Bolt former machine operates using high horse power to cold forge steel wire into shaped products. The machine can be dangerous if input parts are loose or misplaced, which may lead to machine rupture and explosion.

- The operator who assembles toolings including dies, punches and wire toolings, must be the same operator to perform trial runs and adjustment. By doing trial runs and adjustment, operator needs to be sure that all inputs are properly assembled using the right toolings with no loose parts. The only way to ensure this is to do it himself.
- The maximum of two operators are able to work on the setup operation in normal working days.

4.1.4 Specify research time frame

- This research is expected to be finished within 3-6 months. The duration for this research is from April to September 2016.

4.2 Improvement phase

Once the planning phase clarifies all necessary information, the improvement phase describes methodology to execute this research. Setup operation is a subjective matter upon different types of machines. Therefore, this project has developed framework as standard procedure for setup time improvement project.

4.2.1 Improvement Framework

The setup time improvement framework is established base on the theories and literatures review, and adapted to be two steps improvement framework as shown in Figure 23. The first step is SMED setup time improvement, using the traditional tool for setup time reduction of Single minute exchange of dies (Dillon and Shingo, 1985). The second step, Refined setup time improvement is developed to provide further analysis and improvement of the operation. Lean tools and techniques are used in order to capture the setup operation areas that are neglected in SMED. Two steps improvement framework is expected to maximize the setup time reduction result.

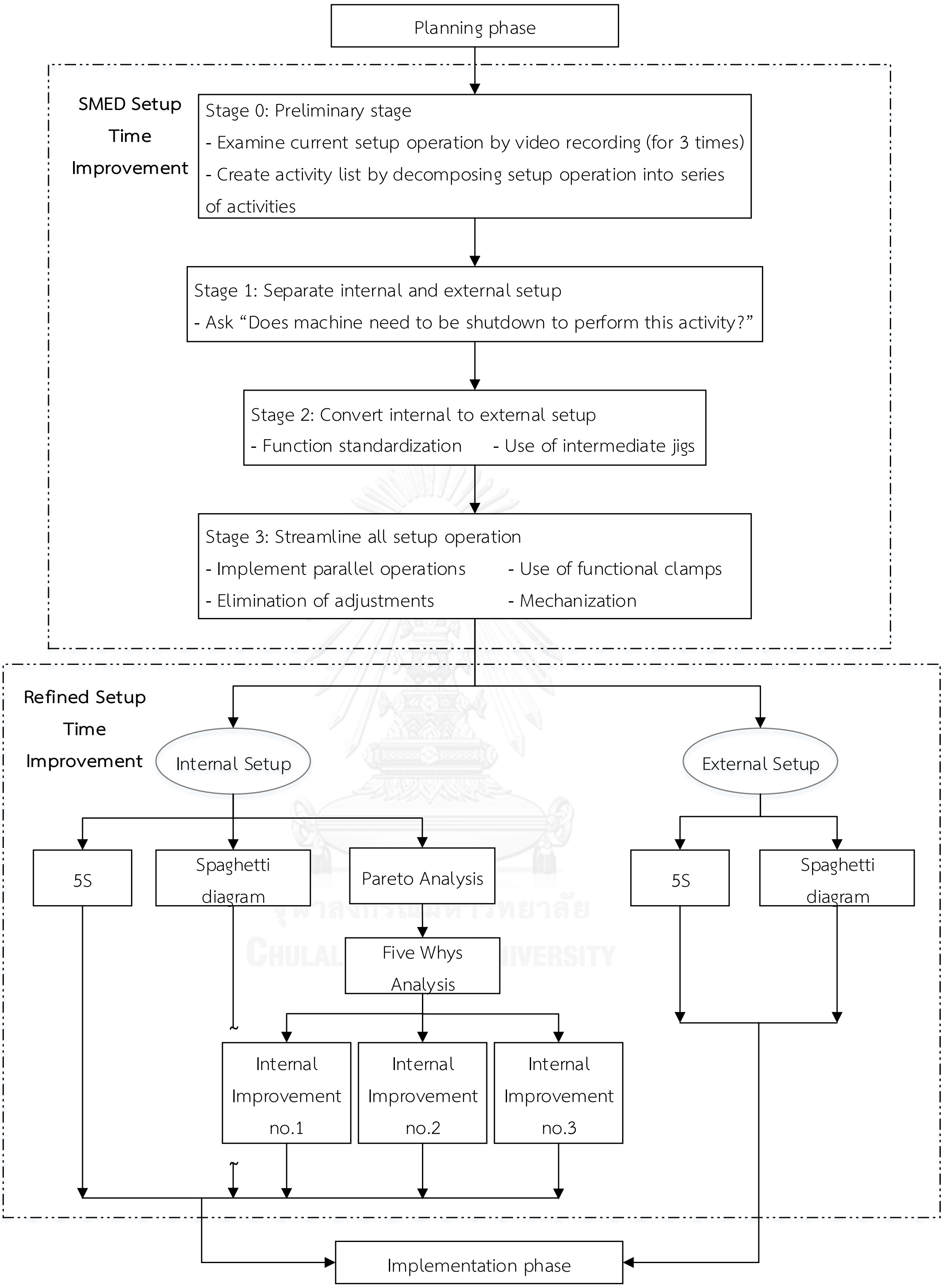


Figure 23: Setup time improvement framework

4.2.2 SMED Setup Time Improvement

The start of improvement applies the concept of Single minute exchange of dies (SMED), which is a conventional tool for reducing setup time and improving setup operation. SMED consists of four conceptual stages with practical improvement techniques suggested in each stage. With many practical techniques in the book written by (Dillon and Shingo, 1985), this research considers the eight widely used practical techniques. These eight practical techniques are successfully implemented as shown in researches by (Joshi and Naik, 2012) and (Deros et al., 2011).

It is important to understand the terms and definitions that are frequently used in this research as follows:

Internal setup: the operation that needs to be done only when machine is stopped. Therefore, internal setup activities define setup time.

External setup: the operation that can be done while machine is running.

Setup time: the actual time taken to changeover from producing the last good piece of previous production lot to the first good piece of next production lot with quality control personnel approval.

As shown in Figure 24, the setup time definition in this research is modified from the conventional meaning. Even though the first piece product is produced, the setup operation is not counted as finish until product quality is approved by quality control personnel.

Figure 24: Definition of setup time

Stage 0: Preliminary stage

Preliminary stage of SMED involves examining current setup operation. Data and detail of setup operation are recorded by video recording method and listed in activity log sheet.

Video recording

Video recording method is more beneficial comparing to other observation techniques. The camera man is not distracted by other tasks except filming ongoing operation. Video ensures all details are recorded which can be shown to operators and other related parties to help recognize waste and improvement areas. Video has replay function and time duration displayed which also eliminate requirement of stopwatch. Therefore, video recording ensures the complete and accurate time and data collection.

Activity log sheet

Activity log sheet is a template used to list all activities of setup operation, time taken and types of each activity (internal or external setup). Generally, more detail is better for improvement. However, with long setup time of 4 hours in this research, only main activities are mentioned in activity list, which is adequate for analysis and improvement.

Stage 1: Separate internal and external setup

Distinguish the correct type of activities

According to the activity list created in preliminary stage, each activity is asked "does bolt former need to be shutdown to perform this activity?" regardless of what setup type it is listed in the current operation. It is a simple procedure, none the less, necessary for the improvement. It is often found that external activities are wrongly assumed to be done as internal activities.

After all activities have been correctly separated into internal and external setup, theoretically setup time can be calculated by summing up the remaining of the internal setup operation.

Stage 2: Convert internal to external setup

Referring to the updated list from stage 1, brainstorming session is arranged to convert the remaining internal setup activities to external setup. The widely used practical techniques suggested in SMED system are function standardization and the use of intermediate jigs.

Function standardization

This technique involves standardize sizes and dimension of all machine parts, which leads to standardize tools that are used on those parts (Dillon and Shingo, 1985). Unfortunately, company's constraint limits any modification of all machine parts due to safety issues. And tools cannot be modified if parts in the machine are not modified. Therefore, this technique cannot be done in this research.

Use of intermediate jigs

This technique is considered one of function standardization techniques. Jig can be a device or a plate that guides the tools and supports the production workpiece while being processed. The intermediate jigs refer to the same size and shape of jigs, which allow the next workpiece to be attached and adjusted to the jig as external setup instead of internal setup. Once the previous workpiece is finished, the attached jig and workpiece can be mounted and processed quickly. However, jigs in this research setup operation are not interchangeable. They are fixed to the machine and cannot be easily taken out. If this research were to take them out to create intermediate jigs as suggested by SMED, it would violate the company's constraints of no machine modification. Therefore, this practical technique also cannot be used in this research.

The SMED practical techniques in stage 2 are not suitable for this research. It is concluded that stage 2 of SMED cannot be done for bolt forming setup time improvement.

Stage 3: Streamline all setup operations

The last stage of SMED is simplifying all setup activities, both internal and external setup operations. Various practical techniques are widely used in SMED implementation and being considered in this research.

Parallel operation

The implementation of parallel operation refers to more than one operators working on the same setup operation. Two operators are used in this research due to company's constraint. Parallel operation can significantly reduce setup time if perform effectively. However, safety is an important issue since two operators are working on different activities in a job. Both operators must communicate and ensure safety before performing any continuous activities. In this research, the operator is ought to shout "finished" once activities involving the continuity of another operator are finished. Whistle is also an option for noisy shop floor, but string of whistle can get tangled inside the machine while working on trial runs and adjustment which possibly harmful to operators. Even though shop floor is a bit noisy, but communication is hearable in setup working area.

Elimination of adjustment

Adjustment is the most time consuming activity in setup operation. This technique refers to the elimination, not the reduction of adjustment activity, which can be done by modifying the inaccurate centering and dimensioning of machine and inputs. However, with modification scope which is constrained by company and production is stopped for a long time while bolt former is under investigation. Therefore, this technique is not suitable and is not implemented in this research.

Functional clamps

The implementation of function clamps are the replacement of bolts and nuts for tighten and loosen operations, which accounts for many parts in this research. Instead of turning many times on threads of bolt and nut, this practical technique reduces turning to be only a one-turn operation. Even though bolt former machine can implement this practical technique due to many tighten and loosen operations, it violates safety issue and company constraint not to modify any parts of the machine. Moreover, the author agrees not to implement functional clamps since the machine uses high horse power which only one-turn thread may not be adequate to hold interchangeable parts inside the machine, which can lead to serious rupture and explosion. Therefore, this practical technique is not usable this research.

Mechanization

Mechanization should be the last of all techniques to help reduce setup time. It is effective once setup operation has been streamlined and improved. Mechanization refers to the acquisition of technology to help with setup time improvement such as automated adjustment and remote control tightening and loosening. However, this practical technique involves high investment capital which is also one of the company's constraints. Therefore, this research is not implementing this technique on bolt former.

However, the concept of bringing technology to help with setup operation gives an idea to replace an old weight scale with a digital weight scale. Digital weight scale is able to reduce time to weight the finished products as part of setup operation with only small investment.

4.2.3 Refined Setup Time Improvement

It is predicable that only SMED implementation alone is unable to achieve target setup time reduction. As a result, other lean tools and techniques, and opportunities for coordination and collaboration between internal departments within the company are explored, to further reduce setup time.

The second step of setup time improvement is called refined setup time improvement, by using analyzed data from SMED to continue improving setup time. This step is separated into internal and external setup improvement. As inspired by research of (Ferradás and Salonitis, 2013) to tackle internal and external separately since activities and the importance between two setup types are different.

Internal Setup Operation

The time spends on internal setup operation defines the definition of setup time. Therefore, it is important to identify further improvement areas in internal setup for reducing setup time as much as possible.

Pareto Analysis

From the first step of setup time improvement done using SMED system, the list of activities can be separated into the corrected internal and external setup. According to that list, the remaining internal setup activities are further analyzed using Pareto analysis to find a few activities that contribute to the most of setup time (20/80 rule).

Five Whys

After using Pareto analysis, the Pareto graph exhibits relationship between activities and time loss in descending order. This research selects the vital few of activities that cause the major time loss and uses Five whys analysis to find root causes of the selected activities for further improvements.

Five whys technique is proceeded in an internal meeting with the research team, in order to help brainstorm causes for time loss in the selected activities. By including all team members in this meeting allows different point of views of the problems to be disclosed i.e. from top level manager and from shop floor operators. It also ensures that root causes of the problems are revealed and unbiased. After that, root causes of the selected activities' problems are discussed for the most appropriated and suitable improvements.

Spaghetti Diagram

Spaghetti diagram is used as a mapping tool to analyze the travel distance and movement of operator while working on setup operation. The objective is to improve effectiveness of operator's movement during internal setup operation. The first step as advised in theory review section 2.1.9 is to draw workplace layout with all necessary details for internal setup activities. Then, movement path is drawn as operator travels. Once drawing is completed, travel distance can be reduced and unnecessary travel can be eliminated, which leading to indirectly reduce setup time. Table is created to summarize movements, travel distances and travel times in order to compare the improvement results.

5S System

The 5S system is implemented to improve setup operation efficiency by sort, set in order, shine, standardize and sustain. For internal setup, 5S is implemented on tools that are used during bolt forming internal setup operations including different types of wrenches that are used for adjustment and tighten/loosen parts. The implementation of 5S helps eliminate unnecessary tools in bolt forming area and organize remaining tools. Operator is able to locate the required tools and recognize the missing tools faster which reduce setup time. Moreover, excess movement seen from spaghetti diagram can be used in 5S improvement. The implementation is done using the assigned bolt former (BF 23).

1.) Sort

Current tools in bolt former area are investigated. Lead operator and setup operator need to advice on functions of each tool, to distinguish tools into the ones use in setup operation and ones that are not.

2.) Set in order

The next action is organizing the remaining tools in a structured way for everybody, not only one person, to easily locate them without spending unnecessary time looking. This research uses shadow board technique for improvement. Shadow board allows every single tool to have its own place which is convenient in setup operation and missing tools can be easily noticed.

3.) Shine

Shine is an action to tidy up the working area. The operator must make sure that the setup operation workplace around bolt forming area including bolt former machine, tools and shadow board are tidy and clean on daily basis. As mentioned in 5S System theory review section 2.1.8, cleaning up allows abnormalities to be detected and reported as soon as possible.

4.) Standardize

Standardize the practice of 3S i.e. sort, set in order, and shine in bolt forming area. The company must ensure that 3S is treated as one of the standard procedure and being maintained on a daily basis. Even though this action takes time to see results, this research develops a daily check sheet to ensure that operator at the assigned bolt former are maintaining a good work. Operator is required to inspect cleanliness and abnormalities before signing the check sheet.

5.) Sustain

In order to sustain the improvements, regular audits, and reward and recognition program are recommended as mentioned in section 2.1.8 the 5S System theory review.

<u>External Setup Operation</u>

The external setup operation is activity that can be done during machine is running, which does not affect the setup time. Therefore, improvement of external setup is not as important as those in internal setup. Two lean improvement tools and techniques are considered for external setup time reduction; spaghetti diagram and 5S system.

Spaghetti Diagram

Similar to spaghetti diagram in internal setup improvement, external setup workplace layout with necessary details are drawn. The layouts of internal and external setup are different due to different travel distances and destinations. External setup activities consist of getting finished wire and toolings according to Production order, and return toolings to tooling store once production is finished. As the operator travels for external setup operation, movement paths are drawn in the drawing. The table for external setup is also created to summarize the movements, travel distances and travel times.

5S System

As external setup activities involve the use of finished wire and toolings, the implementation of 5S is difficult to do. First of all, by sorting, setting in order and shining of finished wire do not help with bolt forming setup time reduction. Since finished wire is made by the internal process and stored in wire process area which is far from bolt forming area. Only ordered finished wire is delivered near the assigned bolt former using forklift and overhead crane which no need for 5S implementation. For toolings, the company has more than 50,000 pieces of tooling kept in tooling store. In order to implement 5S as sorting, setting in order and shining of all toolings takes approximately 1 year. Due to time limitation, this research is unable to implement 5S system on the toolings. However, the recommendations are given for tooling store improvement.

4.3 Implementation phase

4.3.1 Preparation for implementation

Once each part of the improvement is finished, all improvements are summarized and trained to two of bolt forming setup operators who are going to work in parallel. The procedures and duties of each operator are described to execute full improvement implementation of Product A without any mistakes or misunderstanding.

4.3.2 Improvement implementation

The full setup improvement implementation is recorded using video recording method as same as the approach for current setup operation data collection.

4.3.3 Post improvement implementation

After successful implementation, standard operating procedure or SOP is created to illustrate step by step of improved bolt forming setup operation.

4.4 Conclusion of Methodology

Methodology of bolt forming setup time improvement is divided into three phase i.e. planning, improvement and implementation phase.

For planning phase, research team is formed and time frame is specified. Moreover, necessary information for the research and research's constraints are also defined.

For improvement phase, setup time improvement framework is developed, consisting of two steps improvement i.e. SMED and refined setup time improvement. Framework is established as a standard method to effectively analyze and improve setup operation.

Single minute exchange of dies (SMED) is considered as the first step for setup time improvement, consisting of four conceptual stages with eight widely used practical techniques. However, many of SMED practical techniques involve machine and tool modifications which are unable to implement in this research due to company's constraints on safety concerns and investment capital. Therefore, improvements that can be implemented in this research are examining current setup operation (stage 0), distinguishing correct type of setup activities (stage 1), and parallel operation and mechanization (stage 3).

The second step, refined setup time improvement is divided into internal and external setup improvement. Internal setup activities define setup time and the improvement starts from Pareto analysis, follows by five whys technique to find root causes of the important activities that contribute to the most setup time loss. After that, spaghetti diagram is implemented to study and improve travel distance of operator. Finally, 5S system is implemented on tools that are used during setup operation for more efficiency ways of operation. For external setup operation, spaghetti is implemented to improve travel distance during external setup. However, 5S system for external setup cannot be implemented in this research due to the limited time frame. Nonetheless, recommendations are given for 5S future improvement project on external setup.

All considered improvements and implementation capabilities for this research are summarized in Table 8 below.

The third phase is implementation phase. Improvement preparation and training are taken place before full implementation is proceeded. Implementation of improved setup operation is done using video recording. And finally, standard operating procedure (SOP) is developed once the implementation is successfully completed.

Table 8: Improvement and implementation summary

Improvement Methodology	Implementation	Remark
1.) SMED Setup Time Improvement		
Stage 0: Preliminary stage		
Examine current setup operation by video recording	Yes	-
Create activity list	Yes	-
Stage 1: Separate internal and external setup		
Distinguish the correct type of activities	Yes	-
Stage 2: Convert internal to external setup		
Function standardization	No	Company constraint
Use of intermediate jigs	No	Company constraint
Stage 3: Streamline all setup operation		
Parallel operation	Yes	-
Elimination of adjustments	No	Company constraint
Use of functional clamps	No	Company constraint
Mechanization	No	High investment for bolt former
	Yes	Implement on weight scale
2.) Refined Setup Time Improvement		
Internal Setup		
Pareto analysis	Yes	-
Five Whys analysis	Yes	-
Spaghetti diagram	Yes	-
5S system	Yes	-
External Setup		
Spaghetti diagram	Yes	-
5S system	No	Recommendations are given

Chapter 5 Process Improvement and Implementation

After all process improvement concepts had been described in the previous chapter, methodology, this chapter illustrates the actual implementation of process improvements following steps in the setup time improvement framework. Full improvement implementation of bolt forming setup operation is also demonstrated at the end of this chapter.

5.1 Process Improvement

5.1.1 SMED Setup Time Improvement

Stage 0: Preliminary stage

Video recording was started when operator received Production order. The activity began with preparation of raw material and continued until the operator returned toolings to the tooling store. The current setup operation observation by video recording had been performed three times and all sub-activities details were recorded in activity log sheet as shown in Appendix B1. There was no significant time difference between the three times of data collection since setup operation was a repeated procedure. Therefore, it was assured that the three collected data represented normal setup operation time for bolt forming setup operation. As mentioned in Planning Phase section 4.1.1, three collected data were considered adequate and reliable to perform further analysis.

Author selected data from the longest setup time among three observations to represent the worst case scenario of setup operation. The selected main setup activities, duration, and setup type are shown in Table 9.

Table 9: Current setup operation activity list

Step	Activity	Duration (h:mm:ss)	Setup type
1	Prepare finished wire	0:07:12	External
2	Prepare dies and punches	0:25:45	External
3	Stop the machine once previous products production is finished	0:02:09	Internal
4	Weigh previous products	0:08:15	Internal
5	Fill in Self-Inspection Check Sheet and Production Report for previous products	0:08:12	Internal

Step	Activity	Duration (h:mm:ss)	Setup type
6	Dismount the previous dies and punches out of machine	0:10:08	Internal
7	Dismount the previous wire toolings out of machine	0:03:12	Internal
8	Dismount the previous grippers out of machine	0:02:11	Internal
9	Dismount the previous feeding rollers out of machine	0:05:06	Internal
10	Clean up the previous dies and punches	0:23:47	Internal
11	Mount new wire toolings onto machine	0:06:26	Internal
12	Mount new feeding rollers onto machine	0:09:11	Internal
13	Connect finished wire onto machine	0:14:12	Internal
14	Mount new grippers onto machine	0:05:38	Internal
15	Mount new dies and punches onto machine	0:39:12	Internal
16	Trial runs and adjustment of dies, punches and wire toolings (the cycle was repeated 32 times) *Note1	0:49:45	Internal
17	Test run machine at production speed	0:06:28	Internal
18	Fill in First Piece Inspection Check Sheet	0:12:09	Internal
19	Inspect the finished products by Quality Control personnel (first time)	0:01:55	Internal
20	Rework on problematic area of setup operation	0:33:21	Internal
21	Inspect the finished products by Quality Control personnel (second time)	0:08:03	Internal
22	Return dismantled dies and punches to the storage	0:09:18	External

Note 1: Trial runs and adjustment consisted of repeated activities as explained in detail in Appendix B3, Note 1.

Current setup operation was listed into 22 steps of activities with internal setup and external setup of 19 steps and 3 steps, respectively. The durations of internal and external setups are summarized in Table 10. As internal setup activities represented the definition of setup time. Therefore, the current setup time is 4 hours 9 minutes and 20 seconds.

Table 10: Current setup time summary

Detail Summary	**Time (h:mm:ss)**
	Stage 0
Setup Time	4:09:20
External Setup Time	0:42:15

For better understanding of setup operation processes, the following figures were snapshotted from video recording to illustrate main setup activities in operational sequences. Some of the steps contained more than one picture for more detailed description of the activities.

Figure 25: Step 1 Preparation of finished wire

Figure 26: Step 2 Preparation of dies and punches in tooling store

Figure 27: Step 3 Stop the machine once previous production is finished

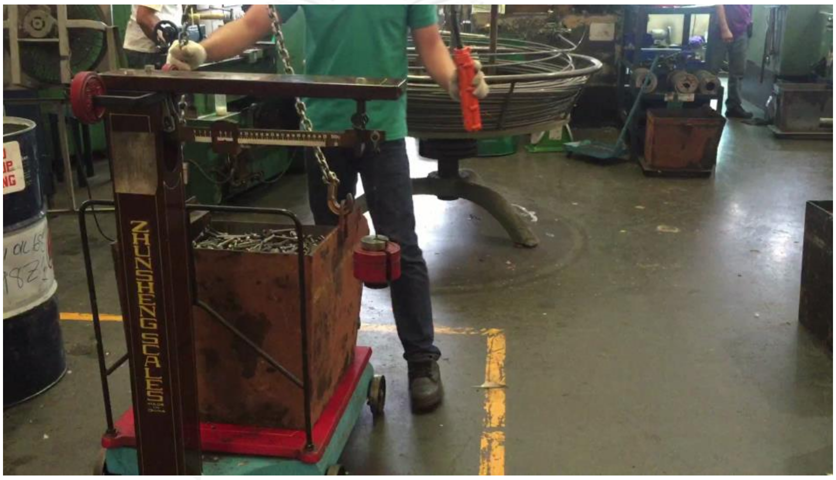
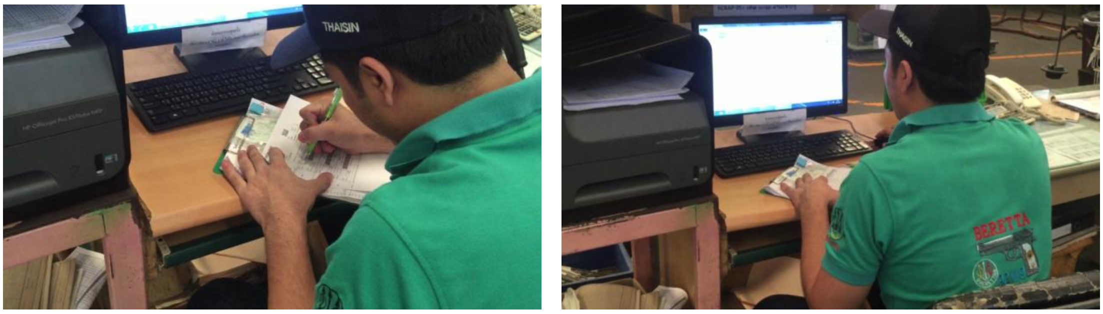


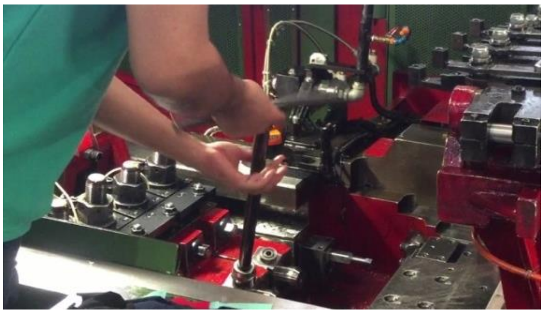
Figure 28: Step 4 Weigh previous products using weight scale



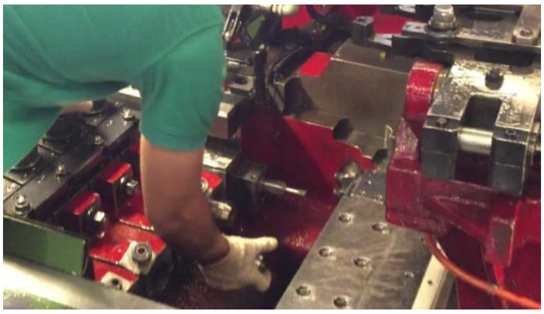
i) Fill in Self-Inspection Check Sheet

ii) Fill in Production Report in computer

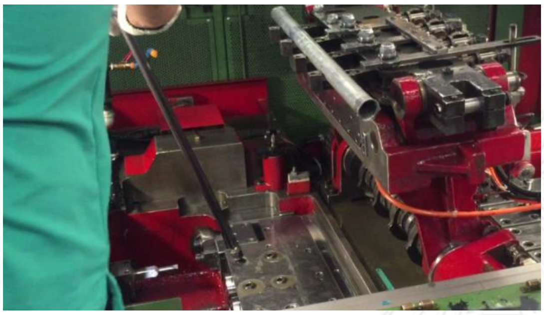
Figure 29: Step 5 Fill in Self-Inspection Check Sheet and Production Report for previous product



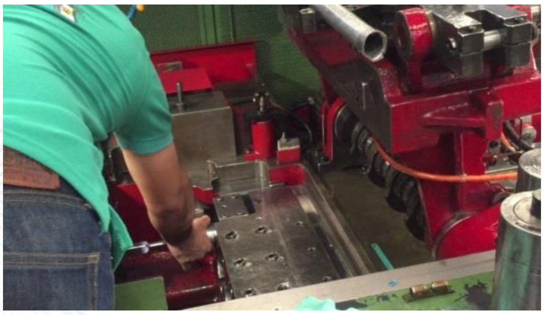
i) Loosen nuts on punch side



ii) Remove punches out of machine



iii) Loosen nuts on die side



iv) Remove dies out of machine

Figure 30: Step 6 Dismount the previous dies and punches out of machine

Figure 31: Step 7 Dismount the previous wire toolings out of machine

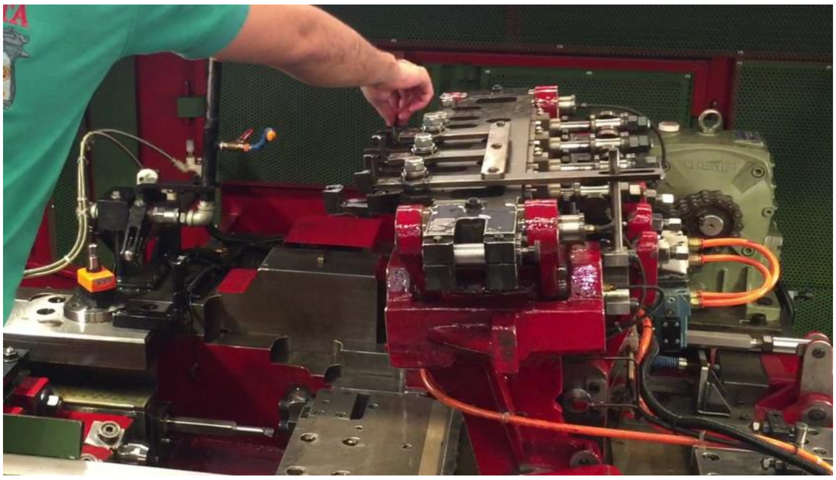


Figure 32: Step 8 Dismount the previous grippers

Figure 33: Step 9 Dismount the previous feeding rollers

Figure 34: Step 10 Clean up the previous dies, punches and wire toolings

Figure 35: Step 11 Mount new wire toolings onto machine

Figure 36: Step 12 Mount new feeding rollers onto machine

Figure 37: Step 13 Connect finished wire onto machine

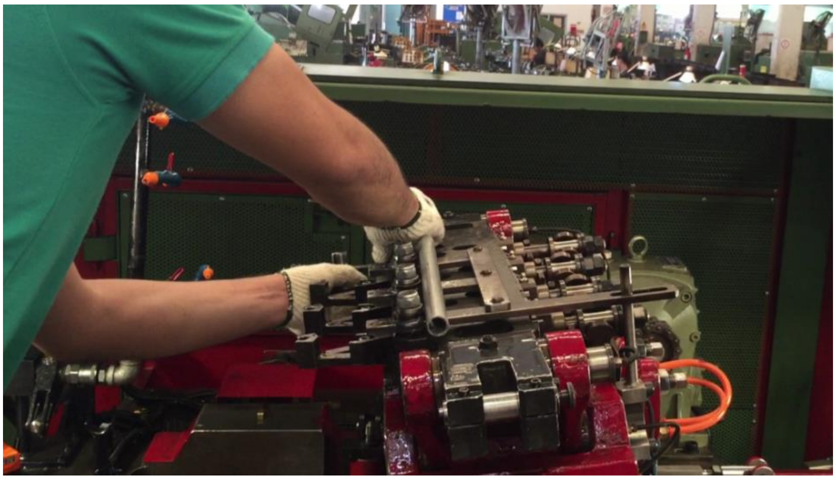
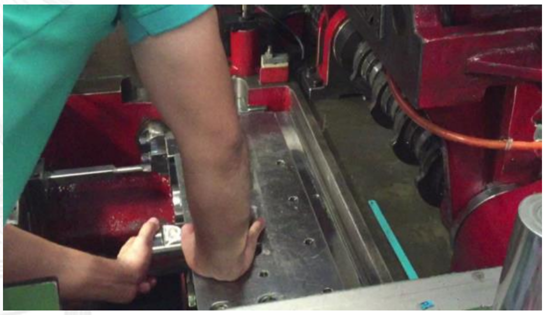


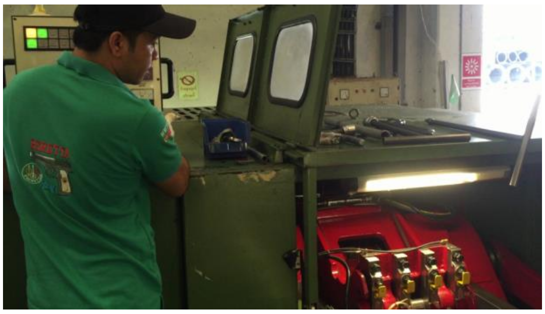
Figure 38: Step 14 Mount new grippers onto machine

i) Mount new punches onto machine



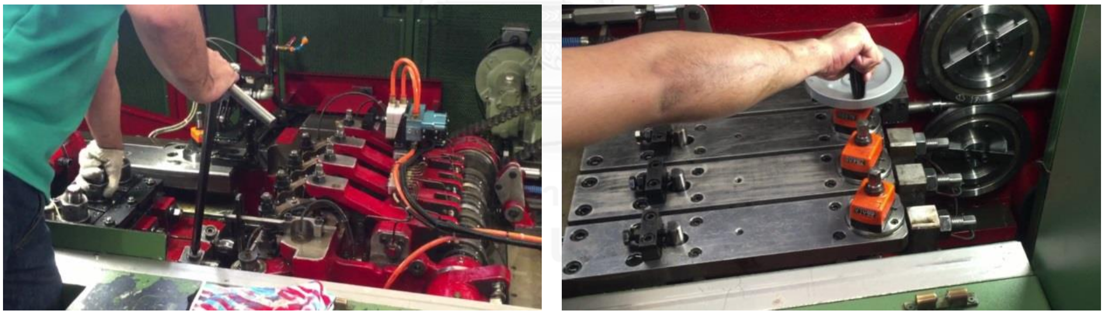
ii) Mount new dies onto machine

Figure 39: Step 15 Mount new punches and dies onto machine



i) Jog machine

ii) Pick up product from gripper and check sizes of product using measuring tools



iii) Make adjustment on punch side (left) and die side (right)

Figure 40: Step 16 Trial runs and adjustment

Trial runs and adjustment consisted of three main activities repeated in cycle as shown in figure i) through iii). The operator must repeat this cycle until the produced product at step 4 was in exact dimensions as stated in Production order. Trial runs and adjustment was considered the most time consuming activity in setup operation.

Figure 41: Step 17 Test run machine at production speed

Figure 42: Step 18 Fill in First Piece Inspection Check Sheet

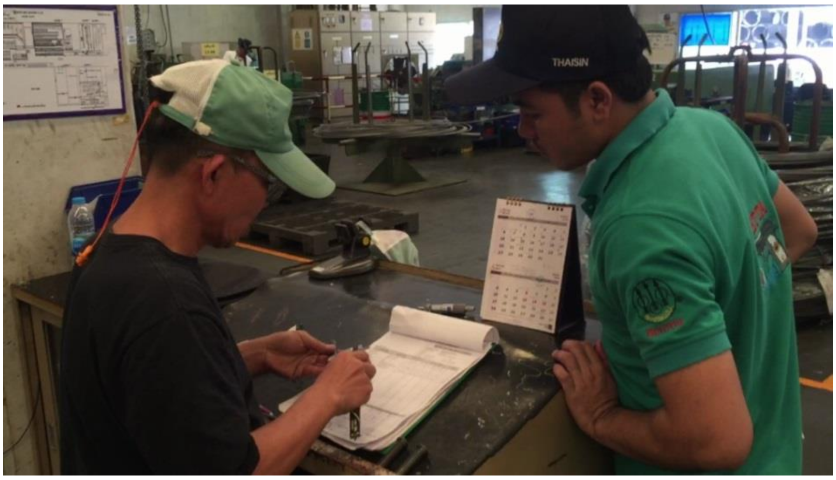


Figure 43: Step 19 Inspect finished products by quality control personnel (first time)

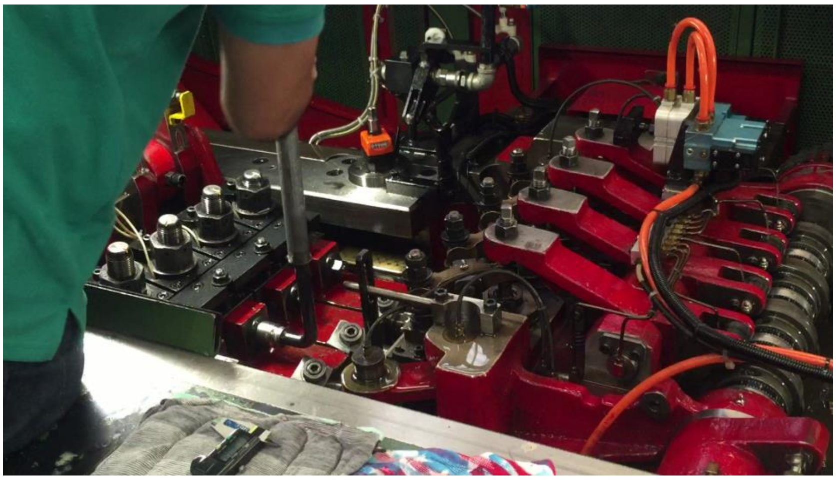


Figure 44: Step 20 Rework on problematic area of setup operation

The quality control personnel did not approve the product from the operator due to quality problems. Therefore, operator was required to correct the issues by reworking on setup operation. Detail of rework activities are explained in Note 3, Appendix B3.

Figure 45: Step 21 Inspect finished products by quality control personnel (2nd time)

Once quality control personnel approved the product quality, the operator was able to start the production.

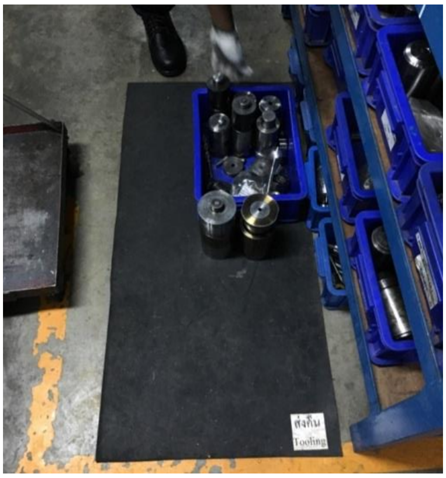


Figure 46: Step 22 Return dismantled dies and punches to the storage

<u>**Stage 1: Separate internal and external setup**</u>

According to the current setup operation activity listed in Table 9 from preliminary stage, each activity was properly distinguished into a proper setup type by simply asking “does bolt former need to be shutdown to perform this activity?” The result of SMED stage 1 is shown in Table 11.

Table 11: Activity list after SMED stage 1 improvement

Step	Activity	Duration (h:mm:ss)	Setup type	
1	Prepare finished wire	0:07:12	External	
2	Prepare dies and punches	0:25:45	External	
3	Stop the machine once previous products production is finished	0:02:09		Internal
4	Weigh previous products	0:08:15	External	~~Internal~~
5	Fill in Self-Inspection Check Sheet and Production Report for previous products	0:08:12	External	~~Internal~~
6	Dismount the previous dies and punches out of machine	0:10:08		Internal

Step	Activity	Duration (h:mm:ss)	Setup type	
7	Dismount the previous wire toolings out of machine	0:03:12		Internal
8	Dismount the previous grippers out of machine	0:02:11		Internal
9	Dismount the previous feeding rollers out of machine	0:05:06		Internal
10	Clean up the previous dies and punches	0:23:47	External	~~Internal~~
11	Mount new wire toolings onto machine	0:06:26		Internal
12	Mount new feeding rollers onto machine	0:09:11		Internal
13	Connect finished wire onto machine	0:14:12		Internal
14	Mount new grippers onto machine	0:05:38		Internal
15	Mount new dies and punches onto machine	0:39:12		Internal
16	Trial runs and adjustment of dies, punches and wire toolings	0:49:45		Internal
17	Test run machine at production speed	0:06:28		Internal
18	Fill in First Piece Inspection Check Sheet	0:12:09	External	~~Internal~~
19	Inspect the finished products by Quality Control personnel (first time)	0:01:55		Internal
20	Rework on problematic area of setup operation	0:33:21		Internal
21	Inspect the finished products by Quality Control personnel (second time)	0:08:03		Internal
22	Return dismantled dies and punches to the storage	0:09:18	External	

There were four external activities that had been done as internal setups in the current operation i.e. weigh previous products, fill in Self-Inspection Check Sheet and Production Report for previous products, clean up the previous dies and punches, and fill in First Piece Inspection Check Sheet. Once these four activities had been brought into external setups, setup time had reduced theoretically to 3 hours 16 minutes and 57 seconds as shown in Table 12.

Table 12: Theoretical setup time summary after SMED stage 1 improvement

Detail Summary	Time (h:mm:ss)	
	Stage 0	Stage 1
Setup Time	4:09:20	3:16:57
External Setup Time	0:42:15	1:34:38

Stage 2: Convert internal to external setup

As mentioned in the Methodology, stage 2 of SMED system suggested improvements by function standardization and use of intermediate jigs, which involved machine modifications. Due to company's constraints, stage 2 could not be implemented in this research. Therefore, the theoretical setup time had not reduced further in SMED stage 2 as shown in Table 13.

Table 13: Theoretical setup time summary after SMED stage 2 improvement

Detail Summary	Time (h:mm:ss)		
	Stage 0	Stage 1	Stage 2
Setup Time	4:09:20	3:16:57	3:16:57
External Setup Time	0:42:15	1:34:38	1:34:38

Stage 3: Streamline all setup operations

The improvements of stage 3 were implementing parallel operation and weight scale replacement. SMED suggested that parallel operation should be implemented on internal setup to reduce setup time. For practical operation on a daily basis, two operators were involved with implementing parallel operation. Table 14 shows only internal setup activities with total of 15 activities and duration of 3 hours 16 minutes and 57 seconds theoretically from current record.

Table 14: Current internal setup activity list

Step	Internal Setup Activity	Duration (h:mm:ss)
1	Stop the machine once previous products production is finished	0:02:09
2	Dismount the previous dies and punches out of machine	0:10:08
3	Dismount the previous wire toolings out of machine	0:03:12
4	Dismount the previous grippers out of machine	0:02:11
5	Dismount the previous feeding rollers out of machine	0:05:06
6	Mount new wire toolings onto machine	0:06:26
7	Mount new feeding rollers onto machine	0:09:11
8	Connect finished wire onto machine	0:14:12
9	Mount new grippers onto machine	0:05:38
10	Mount new dies and punches onto machine	0:39:12
11	Trial runs and adjustment of dies, punches and wire toolings	0:49:45
12	Test run machine at production speed	0:06:28
13	Inspect the finished products by Quality Control personnel (first time)	0:01:55

Step	Internal Setup Activity	Duration (h:mm:ss)
14	Rework on problematic area of setup operation	0:33:21
15	Inspect the finished products by Quality Control personnel (second time)	0:08:03
Total Internal Setup Time		**3:16:57**

Parallel Operation

The company had available resources to do parallel operation without hiring new operators. The company currently had total of 25 operators for 24 bolt formers. Each operator was assigned to responsible for specific bolt former. The main responsibilities of each operator were to setup bolt former for production and supervise that bolt former while the production was running. This research was able to ask operators who were not working on their setup operation to help with other machine's setup operation for short period of time. This was possible since the setup operation for each machine occurred every 3 to 5 days. Therefore, there were many available operators who could help with parallel operation. Furthermore, rather than operators almost being free of work while their machines were running, the parallel operation gave some works for operators to do and helped utilize resources in the company more effectively.

The practical solution for daily basis operation must be considered. In order to avoid confusion and unnecessary collision, operator A and B were working on separate working area of bolt former as shown in Figure 47.

Figure 47: Separate working area for operator A and B during setup operation

Operator A was the main operator for setup operation to produce required products and work on the machine platform to do dismount/mount of toolings, and trial runs and adjustment. Operator A was also working on test runs and QC inspections because it was related to operator A's activities, for example, in case the product was rejected by QC, operator A had to perform further trial runs and adjustment.

On the other hand, operator B was working on finished wire related activities where wire stand and feeding rollers were located outside the machine platform, to dismount/mount feeding rollers and connect wire onto the machine.

Moreover, as one of the setup operation constraints mentioned in planning phase, the operator who assembled all toolings must be the one who did trial runs and adjustment, which was in accordance with this parallel operation. The timeline of internal setup parallel operation is shown in Figure 48. By using current setup data achieved in stage 1, parallel operation could reduce setup time further by 28 minutes and 29 seconds. The setup time was reduced to 2 hours 48 minutes and 28 seconds theoretically as shown in Table 15.

Table 15: Theoretical setup time summary after SMED stage 3 improvement

Detail Summary	**Time (h:mm:ss)**			
	Stage 0	**Stage 1**	**Stage 2**	**Stage 3**
Setup Time	4:09:20	3:16:57	3:16:57	2:48:28
External Setup Time	0:42:15	1:34:38	1:34:38	1:34:38

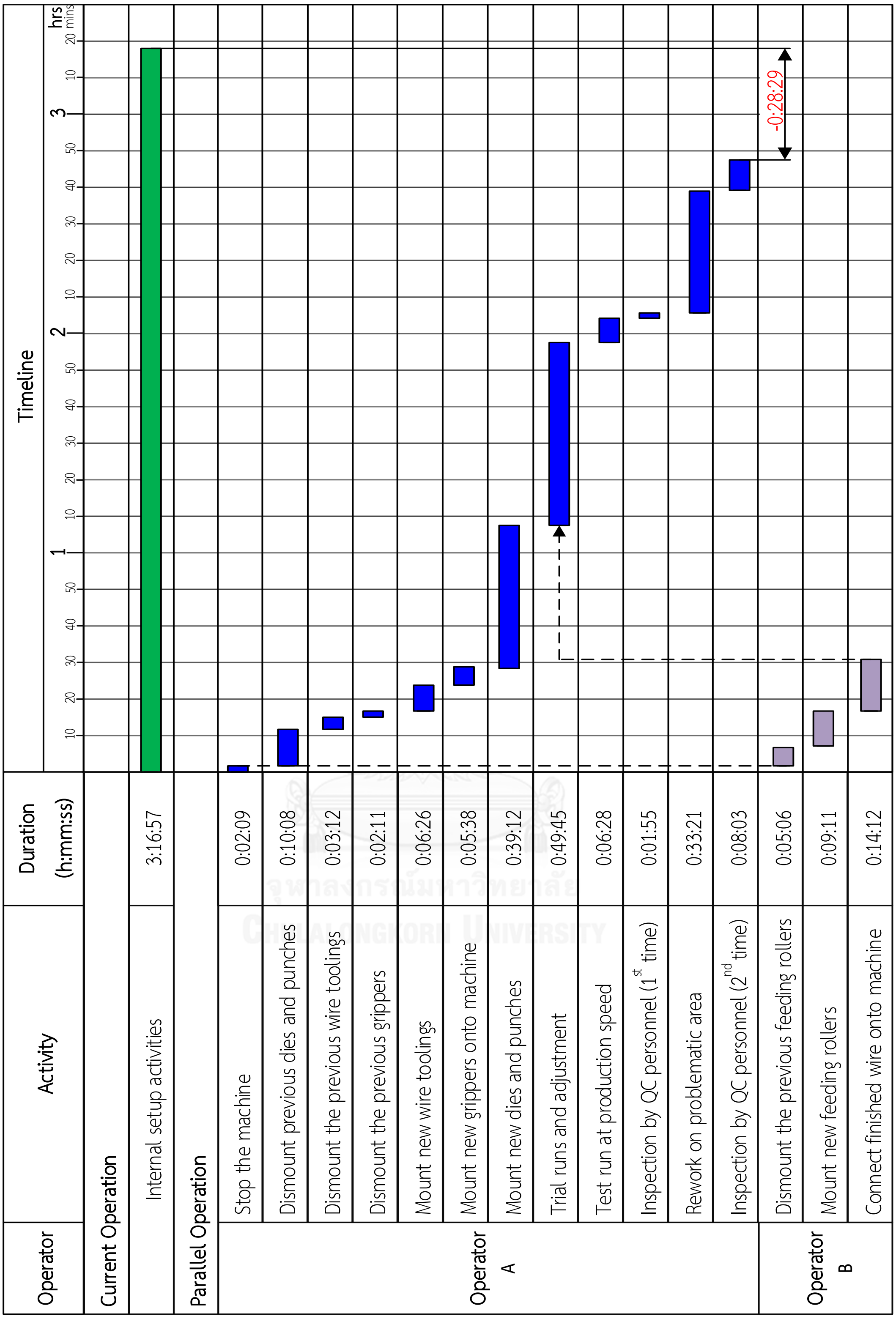


Figure 48: Theoretical result on parallel operation of current internal setup activities

Weight scale improvement

As a part of mechanization to bring technology into setup operation, the old weight scale which used dumbbells to balance the weight of the weighing object was replaced with digital weight scale as shown in Figure 49 and Figure 50.

Figure 49: Old weight scale

Figure 50: Digital weight scale

The digital weight scale worked by hooking it to overhead crane. Operator was able to weigh finished product bin while transporting bin to waiting area. It was not only provided more accurate reading and reduced setup time, but also decreased operator travel distance during weighing activity.

5.1.2 Refined Setup Time Improvement

From four-stage SMED improvement system, theoretically setup time was reduced from 4 hours 9 minutes and 20 seconds to 2 hours 48 minutes and 28 seconds with total reduction of 1 hour 20 minutes and 52 seconds (32.43%), which was not enough to achieve the improvement expectation.

The refined setup time improvement was implementing lean tools and techniques for further analyze problems in setup operation as practical problem solving techniques. Different setup types i.e. internal and external setup were evaluated separately, as internal setup must be further emphasized to directly reduce setup time.

<u>Internal Setup Improvement</u>

According to improvement framework, internal setup improvement used Pareto analysis to identify 20 percent of activities that caused major time loss in setup operation and followed by five whys techniques to find root causes of those problems. Spaghetti diagram was implemented to reduce travel distance during internal setup. Finally, 5S system was used to improve setup operation efficiency.

Pareto Analysis

Table 14: Current internal setup activity list from SMED stage 3 was rearranged to create Pareto graph for internal setup. Pareto analysis had identified a few activities that contributed to the majority of setup time. The graph indicated that 20% of activities (3 out of 15 activities) were accounted for 62.10% of setup time. As shown in Figure 51, three highest times spent on setup operation were caused by trial runs and adjustment, mount new dies and punches into machine, and rework on problematic area, with time of 49 minutes 45 seconds, 39 minutes 12 seconds, and 33 minutes 21 seconds, respectively.

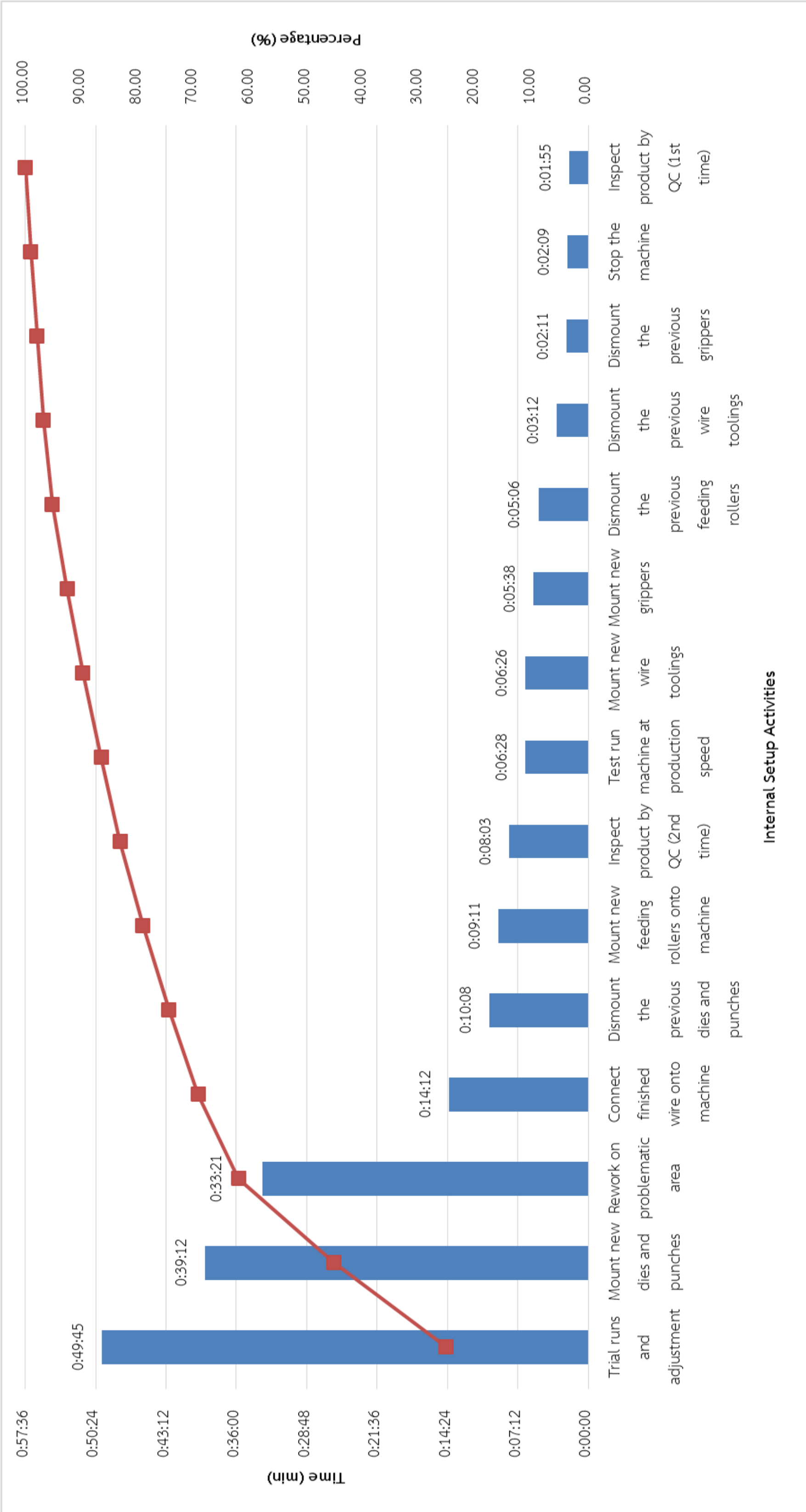


Figure 51: Pareto graph for current internal setup

Five Whys

The three setup activities that caused major setup time loss were further analyzed by five whys technique to find root cause of each problem. The five-why discussions were carried out in brainstorm sessions, consisting of the full research team. The brainstorming detail including the emerged root causes for the three setup activities were illustrated.

Problematic activity no.1: Trial runs and adjustment

The most time consuming activity was trial runs and adjustment of dies punches and wire toolings. The result of five whys are shown in Figure 52.

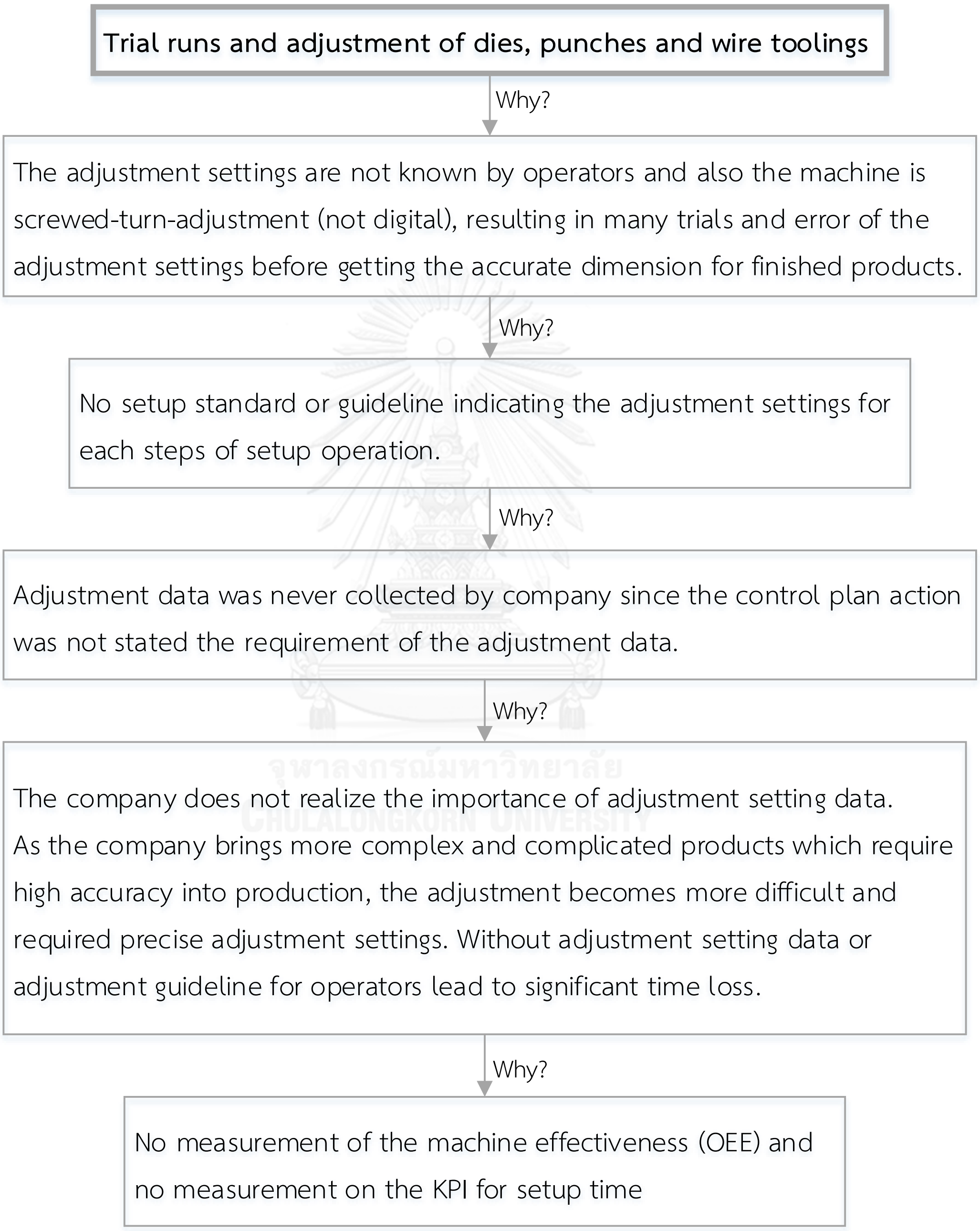


Figure 52: Five-why technique for trial runs and adjustment

- Trial runs and adjustment problem analysis

The root cause for trial runs and adjustment time consuming was because the company had no performance measurement related to effectiveness of bolt formers. Due to inacknowledgement of the importance of quick changeover including the most time consuming activity like trial runs and adjustment.

- Trial runs and adjustment improvement

This research would give recommendations and emphasizes the importance of measuring the key performance or %OEE of bolt formers. However, in order to improve %OEE of bolt former, trial runs and adjustment time had to be brought down, and trial runs and adjustment process had to be improved.

As stated in five-whys causes that the adjustment data was not known because the company did not require anyone to collect that data. In order to reduce setup time, Production manager had decided to make it necessary to include adjustment data in the action plans and assigned operators together with related engineering department personnel to collect these data, which would be useful for future setup operation.

There were total of 17 adjustment parts on bolt former, consisting of;

Punch step 1 through 4 forward/backward: 4

Punch step 1 through 4 upper/lower : 4

Punch step 1 through 4 left/right: 4
(located on the side of the red rectangular, cannot be seen from this view)

Die step 1 through 4 forward/backward: 4

Wire length adjustment: 1

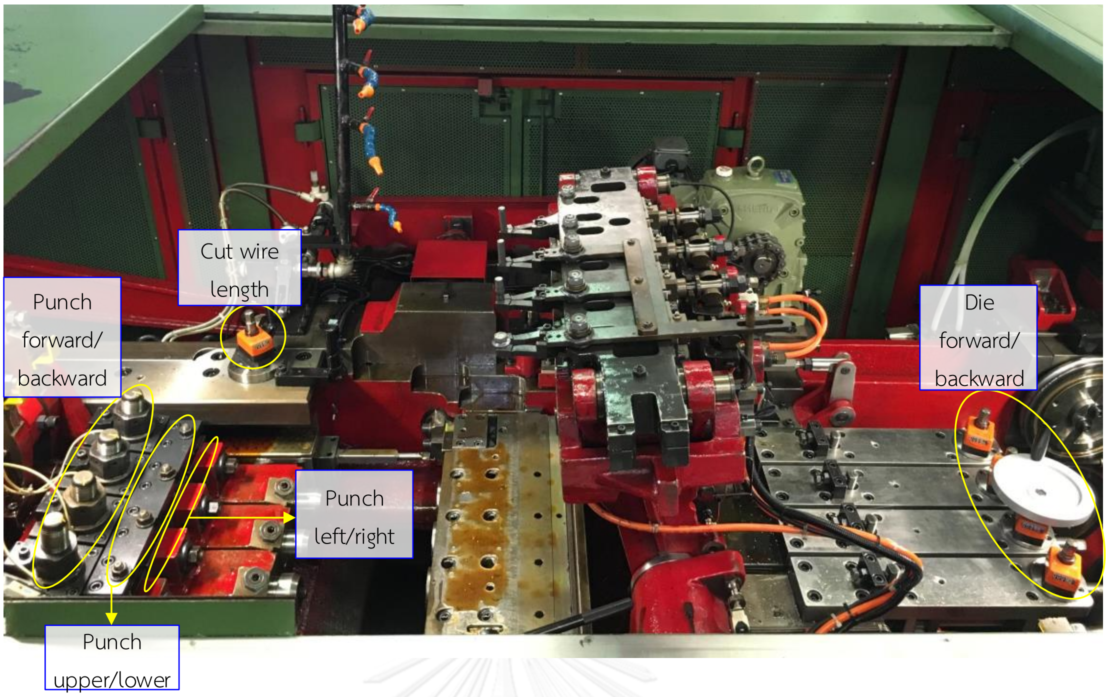


Figure 53: Adjustment detail and configuration in bolt former

As illustrate in Figure 53, adjustment of cut wire length and forward/backward of dies had indicating scale. Therefore, adjustment data could be collected for every product model for future setup time reduction, which in this research was collecting adjustment data for product A as shown in Figure 54. Adjustment data was collected once finished product was approved for production by quality control personnel.

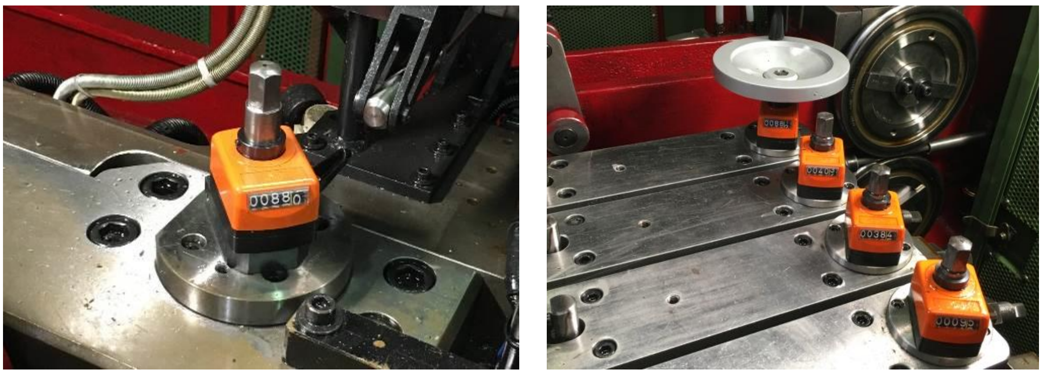


Figure 54: Indicating scales of wire length adjustment (left) and four steps of dies forward/backward adjustments (right)

However, adjustments of punch side had no scale indication. In order to speed up this process, measurement detail of produced product from each step would be given as guidance, instead of only measurement on the final step in Production order. This would allow operator to follow step by step adjustment and prevent operator making adjustment back and forth between four steps which consumed a lot of time. Sample product in each step of production shall be collected and measured as shown in Figure 55.

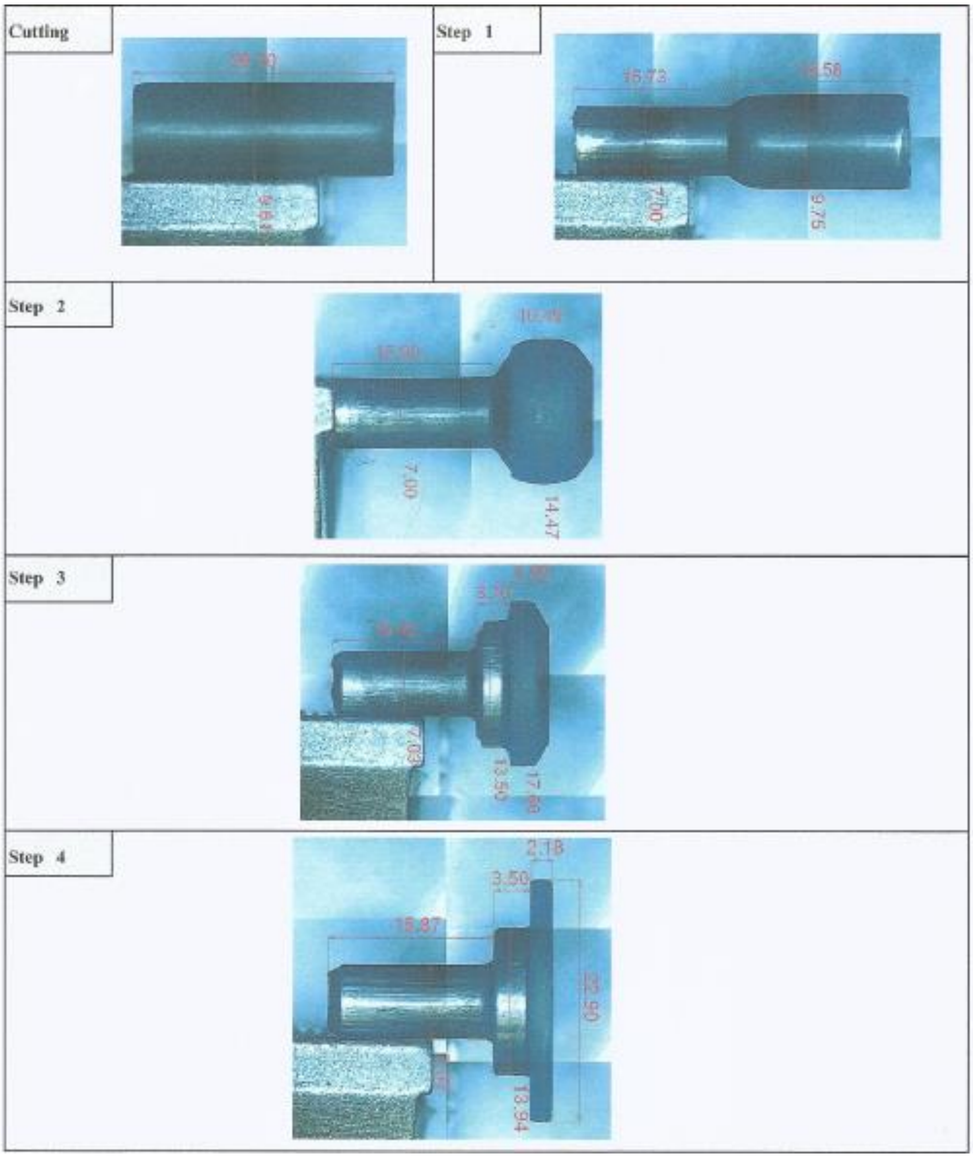


Figure 55: Measurement of produced product in each step

All collected adjustment data were stored in company system under the name Step adjustment guidelline, as a new form of document to help trial runs and adjustmet activity easier and reduce time. For future operation, every product model shall have Step adjustment guideline which would be printed out and used together with Production order, in order to help with setup operation. The setup time of trial runs and adjustment activity was expected to reduce significantly. The example of Step adjustment guideline for product A is shown in Figure 56.

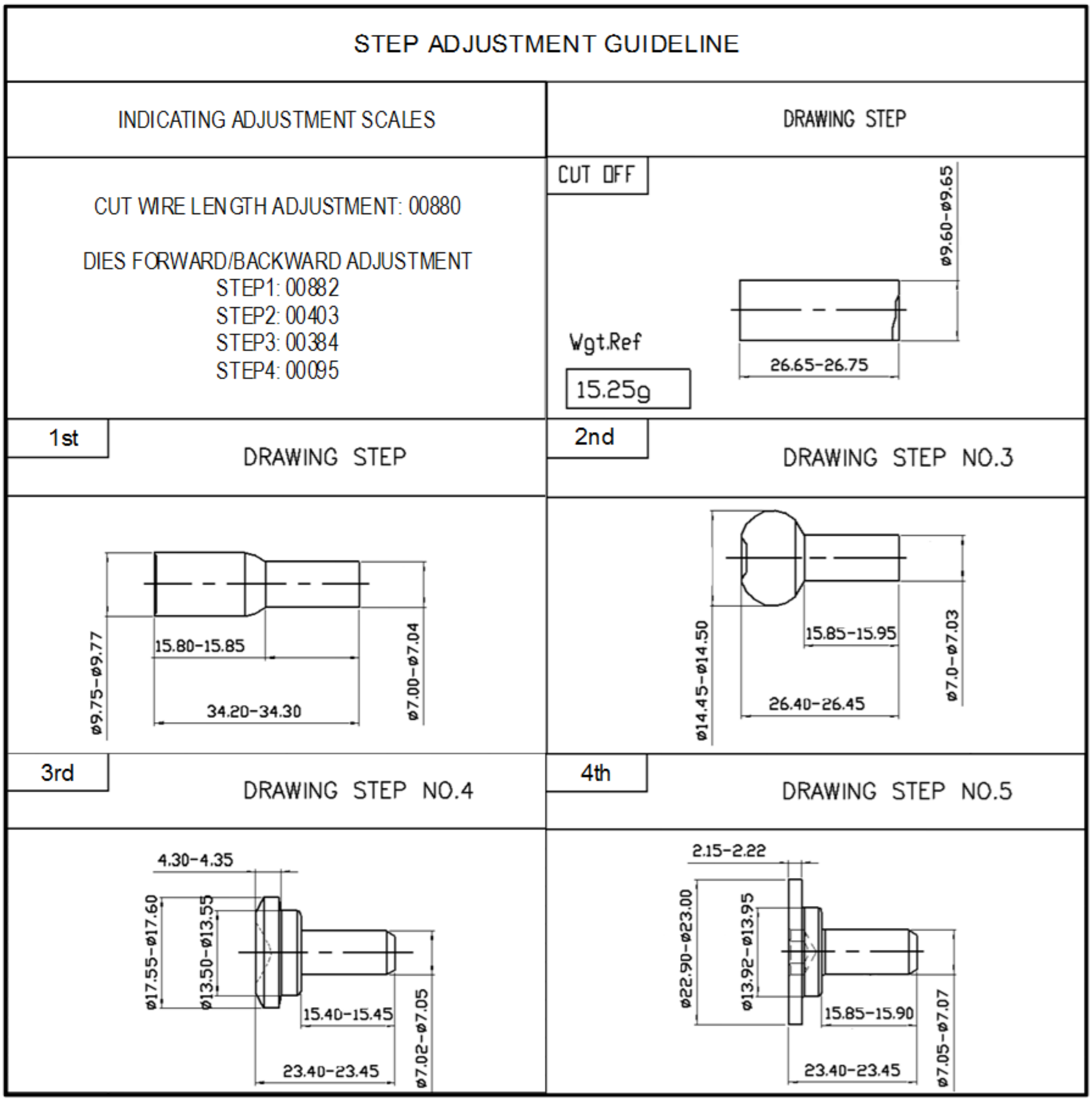


Figure 56: Example of Step adjustment guideline for product A

Problematic activity no.2: Mount dies and punches onto machine

The second consuming time was mounting dies and punches onto machine. The five-whys brainstorming result is shown in Figure 57.

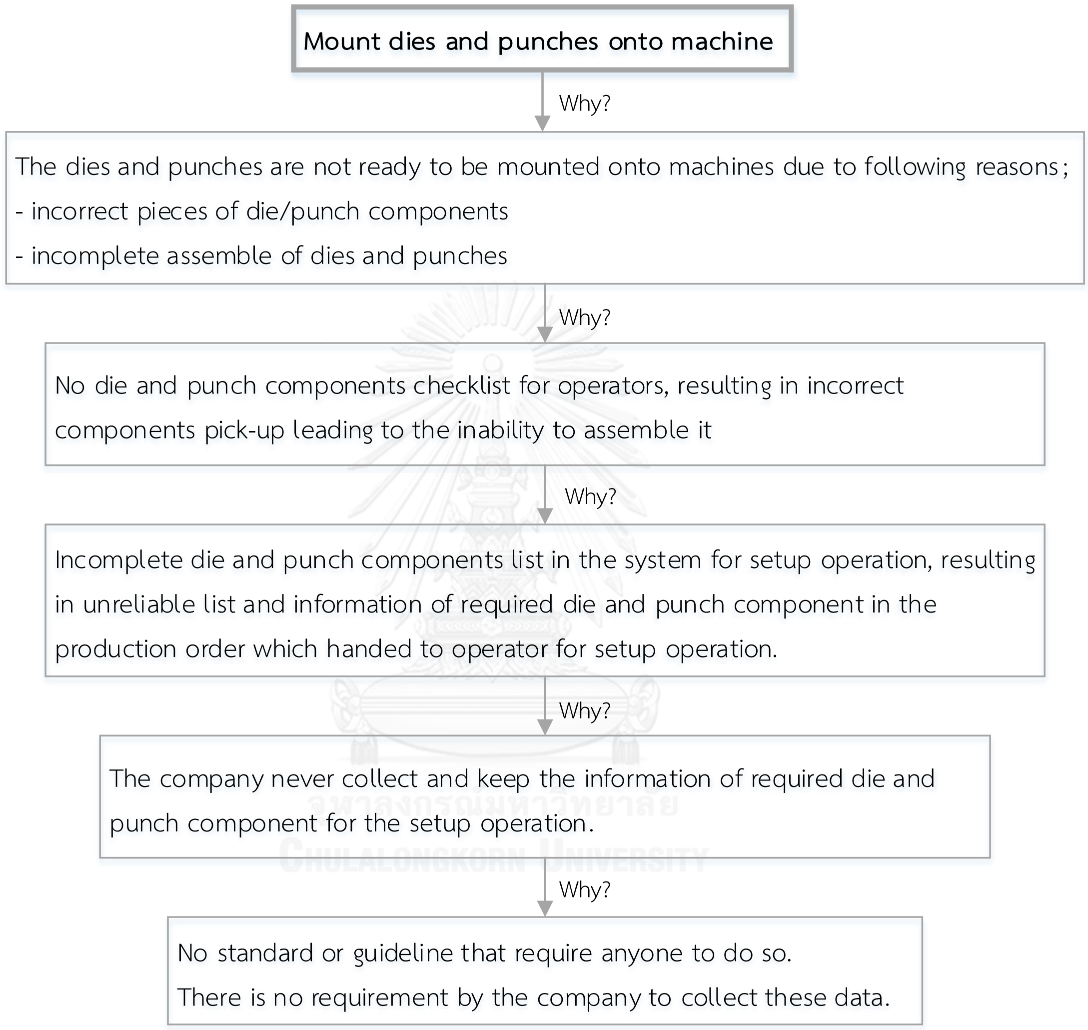


Figure 57: Five-why technique for mounting new dies and punches

- Mounting dies and punches problem analysis

The wasted time was not resulted from mounting dies and punches into machine, but from walking back to store to request new toolings as should be completed during external setup activity. The root cause indicated that the company did not prepare complete tooling list in Production order and did not acknowledge the importance of tooling list for operators.

- Mounting dies and punches improvement

As mentioned in section 3.2 bolt forming setup operation and related internal department, that Engineering department was responsible for listing the required toolings for bolt forming setup operation and the completion of Production order. An internal meeting was arranged comprising or production manager, lead operator and engineering manager to discuss potential coordination between two departments. As a result, engineering manager agreed to complete tooling list to help minimize bolt forming setup time. With coordination between lead operator and engineering department, complete tooling list for product A was finished. The existing tooling list and improved tooling list are shown in Figure 58 and Figure 59, respectively.

No.	Item number	Tooling name	Location
	TE15-1571-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.1 C006491021	TE store
	TE15-1572-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.2 C006491021	TE store
	TE15-1573-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.3 C006491021	TE store
	TE15-1574-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.4 C006491021	TE store
	TE15-1575-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.2 C006491021	TE store
	TE15-1576-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.3 C006491021	TE store
	TE15-1577-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.4 C006491021	TE store
	TE15-1578-01	SECOND PUNCH TIN M8x1.25x19.45 P-SK(SP) 30MM. C006491021	TE store

Figure 58: Tooling list in Production order before improvement

No.	Item number	Tooling name	Category	Location
1	TE15-1571-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.1 C006491021	Die	TE store
2	TE15-1572-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.2 C006491021	Die	TE store
3	TE15-1573-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.3 C006491021	Die	TE store
4	TE15-1574-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.4 C006491021	Die	TE store
5	TE15-1575-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.2 C006491021	Punch	TE store
6	TE15-1576-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.3 C006491021	Punch	TE store
7	TE15-1577-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.4 C006491021	Punch	TE store
8	TE15-1578-01	SECOND PUNCH TIN M8x1.25x19.45 P-SK(SP) 30MM. C006491021	Punch	TE store
9	TE12-1433-01	KO. PIN No.1/6.98X140	Die	TE store
10	TE12-1434-01	KO. PIN No.2/6.98X140	Die	TE store
11	TE12-1435-01	KO. PIN No.3/6.98X140	Die	TE store
12	TE12-1436-01	KO. PIN No.4/5.35X140	Die	TE store
13	TE12-1437-01	KO. PIN Spacer No.1/7.02X12	Die	TE store
14	TE12-1438-01	KO. PIN Spacer No.2/7.02X12	Die	TE store
15	TE12-1439-01	KO. PIN Spacer No.3/7.02X12	Die	TE store
16	TE12-1440-01	KO. PIN Spacer No.4/5.40X12	Die	TE store
17	TE14-0081-01	PUNCH PIN No.2/9.75X65	Punch	TE store
18	TE14-0095-01	PUNCH CASE No.1	Punch	TE store
19	TE14-0098-01	PUNCH Spacer No.1/25.8X55	Punch	TE store
20	TE14-0099-01	PUNCH Spacer No.2/25.8X70	Punch	TE store
21	TE20-1100-01	Cutter 9.85X15	Wire	TE store
22	TE20-1104-01	Cutter(FIXED) 9.85X66	Wire	TE store
23	-	Wire Roller 9.80	Feeding roller	TE store

Figure 59: Complete tooling list in Production order after improvement

The improvement was also required operator to completely assemble toolings as external setup to reduce unnecessary time during internal setup. By completely assembling all toolings, ensured that all toolings were compatible which reduced chances of going to the store during internal setup and that all toolings including sets of dies and punches were ready to be mounted onto machine.

Problematic activity no.3: Rework on problematic area of setup operation

The thrid consuming time was rework on problematic area after the first inspection by QC personnel was not approved.

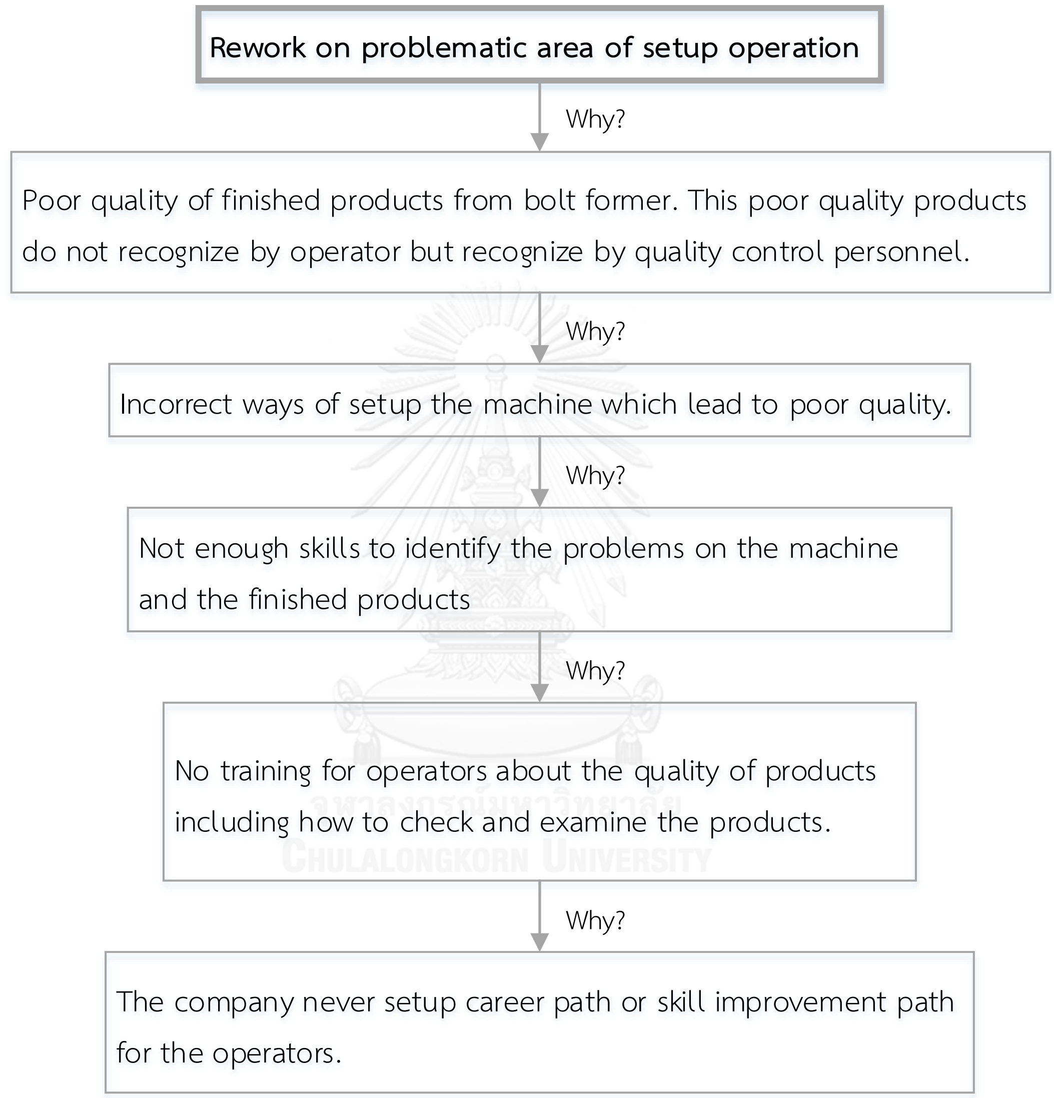


Figure 60: Five-why technique for rework on problematic area

- Rework activity problem analysis

The rework activity was unnecessary for setup operation and should be eliminated. The root cause concluded that the company neglected career path of operators. Therefore, no training was ever provided, leading to unskilled operator that could not distinguish poor quality to good quality product.

An internal meeting was setup between the research team and two quality control personnel to interview and analyze common mistakes occurred on a daily basis and potential coordination solution to eliminate rework activities.

- Rework activity improvement; training program

This research had initiated coordination between operators and quality control personnel to setup training program. The solution for the root cause of the problem was skills improvement for operators. Training program was divided into introduction to bolt forming setup operation, and lunch and learn sessions.

The first training was introduction to bolt forming setup operation which prepared for new operators. As the company often recruited new operators to replace the ones who quit, this training would be mandatory and suitable for new operators to understand the work before starting actual setup operation on shop floor. Detail of training list is shown in Appendix C.

The second training program was called lunch and learn. Lunch and learn sessions would be arranged monthly during lunch time which the company was agreed to provide lunch for all participants. The session would be led by main speaker, using PowerPoint presentation to discuss useful topics related to setup operation. The sessions should be attended by all operators as opportunities to gain more knowledges and skills which would be helpful in setup operation. The contents for lunch and learn must be discussed internally to start setting skill improvement path for all operators. Furthermore, lunch and learn sessions would allow operators to discuss and share experiences which may benefits setup operation in overall.

- Rework activity improvement; target value

During three times of current setup observations, quality control personnel did not approved sample product for all three times. In each observation, rework activities were caused by different problems as detail mentioned in Appendix B3 (Note 3), that was, scratch marks were found on product, symmetry of product was unbalanced, and product size was too close to maximum allowable value.

As to the immediate solutions for three detected rework activities from current setup observations, a training session would be arranged for QC personnel to explain reasons that led to reworks and common mistakes found in product A setup operation. Therefore, operators would know what to look for during the improvement implementation to eliminate rework and reduce setup time as an example of training program.

However, appearance problems of scratch marks and unbalanced product symmetry were easily acknowledged by operator if trained, but appropriate allowance values for different parts of product cannot be memorized by operator such as length of bolt body and size of bolt head. Therefore, target values were provided with the existing allowance value in Production order as shown in Figure 61. Operator would be able to adjust product to get as close to target values as possible to avoid rework activities.

No.	Description	Note
1	Body width (ความโตช่วงรีดเกลียว)	7.05 - 7.09 [Target 7.07]
2	Body length (ความยาวช่วงรีดเกลียว)	15.70 - 15.95 [Target 15.70]
3	Total bolt length (ความยาวช่วงรีดเกลียว+วัดรวมบ่า)	23.50 +/- 0.2 [Target 23.50]
4	Head thickness (ความหนาหัว)	2.10 - 2.40 [Target 2.25]
5	Shoulder width (ความโตบ่า)	13.95 - 14.03 [Target 13.95]
6	Head width (ความโตหัว)	22.50 - 23.00 [Target 22.90]
	FIBER FLOW	FLOW continuous

Figure 61: Allowance values in Production order with additional target values

Spaghetti Diagram for internal setup

First of all, workplace layout with necessary details for internal setup activities was drawn, using current setup operation information from SMED preliminary stage. The layout was not drawn to exact scale in order to clearly emphasize important elements during internal setup. Travel distance was identified using mobile application.

The spaghetti diagram for operator travel paths during current internal setup are shown in Figure 62. Table 16 shows the summary of each travel path operator took, including travel details and travel distances.

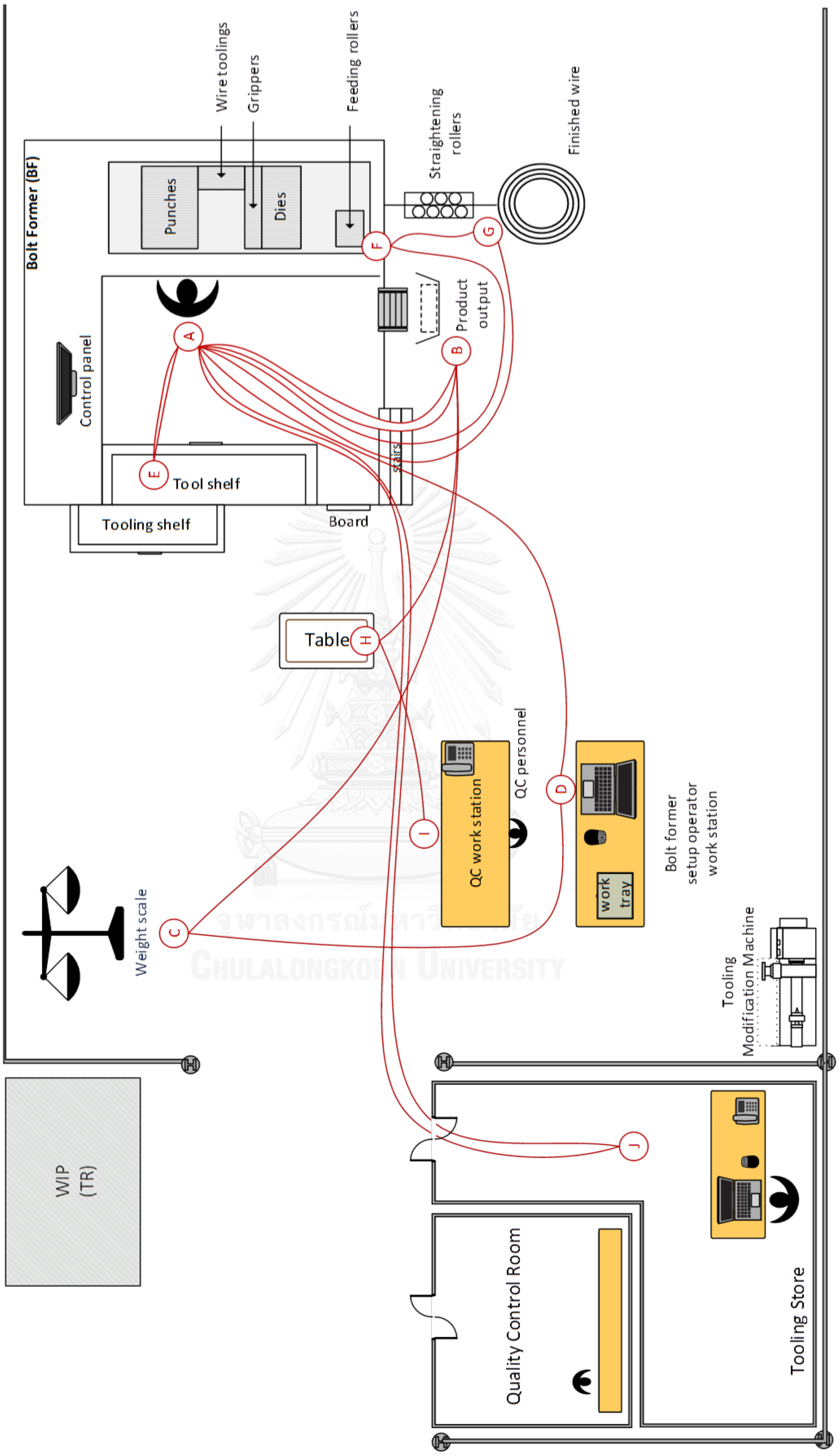


Figure 62: Spaghetti diagram for current internal setup

Table 16: Current internal setup travel summary

Route	From/To	Activity	Distance (m)
1	A/B	Transfer previous finished products from product outlet tray into the bin	3
2	B/C	Weight the previous finished products	15
3	C/D	Fill in previous self-inspection check sheet and production report	5
4	D/A	Walk back to bolt former to start setup operation	10
5	A/E/A	Find tools for dismount and mount all toolings	0
6	A/F	Dismount and mount feeding rollers	4
7	F/G	Connect finished wire to the machine	1
8	G/A	Walk back to continue with setup operation	5
9	A/J	Walk to tooling store to find required toolings	20
10	J/A	Walk back from store to continue with setup operation	20
11	A/B	Check finished product at production speed	3
12	B/H	Fill in first piece inspection check sheet	4
13	H/I	Inspect finished product by QC personnel	10
Total distance			100

Operator traveled total of 100 meters during internal setup with 13 travel paths. From analysizing spaghetti diagram, the only unnecessary travels were route 9 and 10, where operator was required to pick up new toolings from the store, which should have been done during toolings preparation as external setup. However, these routes were believed to be eliminated as completed tooling list had been created and revised in Production order as mentioned earlier.

The rest of travel paths taken by operator were all essential to complete setup operation. Therefore, internal activities travel distance could not be eliminated or reduced further.

5S System for internal setup

The 5S system for internal setup improvement was implemented on tools use during setup operation such as adjustment and tighten/loosen parts inside the machine, which were different types of wrenches. In current situation, tools could be found in tool boxes and around bolt forming area as shown in Figure 63 and Figure 64. The unorganized location of tools resulted in difficulty of finding required tools during setup operation which led to unnecessary time loss.

Figure 63: Tool boxes on bolt former tool shelf

Figure 64: Tools in bolt forming area

Tools management for setup time improvement by 5S system is as follows;

1.) Sort

The tools in tool boxes and bolt forming area were distinguished into the ones that were used for setup operation and the ones that were not. Different size and type of wrenches were matched with adjustment and tighten/loosen parts in the machine using Figure 15 and Table 4 from section 3.1.2 bolt former adjustment and lock parts. Table 17 was created to prevent misallocation of any tools.

Table 17: Detail of tools usage during bolt forming setup operation

No.	Category	Function	Description	Tool	Size
1	Punch	Adjustment	Forward/backward adjustment	Open end wrench	60
2	Punch	Lock	Forward/backward adjustment lock	Hex key wrench	8
3	Punch	Adjustment	Upper/lower adjustment	Open end wrench	24 x 27
4	Punch	Adjustment	Left/right adjustment	Open end wrench	17 x 14
5	Punch	Lock	Upper/lower and left/right adjustment lock	Open end wrench	30 x 32
6	Punch	Lock	Punch position lock (double lock)	T-handle socket wrench	12
7	Punch	Lock	Punch position lock (double lock)	T-handle socket wrench	30
8	Wire	Adjustment	Cut wire length adjustment	Manual scale	
9	Wire	Lock	Cut wire length adjustment lock	Hex key wrench	5
10	Wire	Lock	Wire toolings position lock	Hex key wrench	12
11	Wire	Lock	Wire toolings position lock	Hex key wrench	8
12	Die	Lock	Die position lock	T-handle socket wrench	12
13	Die	Adjustment	Forward/backward adjustment	Manual scale	
14	Die	Lock	Forward/backward adjustment lock	Open end wrench	19 x 22
15	Gripper	Lock	Grippers position lock (adjust manually and tighten lock)	Hex key wrench	6
16	Feeding roller	Lock	Feeding roller position lock	Hex key wrench	10

After all the tools that were used in setup operation were known, unnecessary tools were separated out of bolt forming area.

2.) Set in order

Once all necessary tools for setup operation were known, the next step was to organize tools in structure ways by using shadow board technique as shown in Figure 65 and Figure 66. Shadow board allowed each tool to have its own place and easily spotted the ones that were missing.

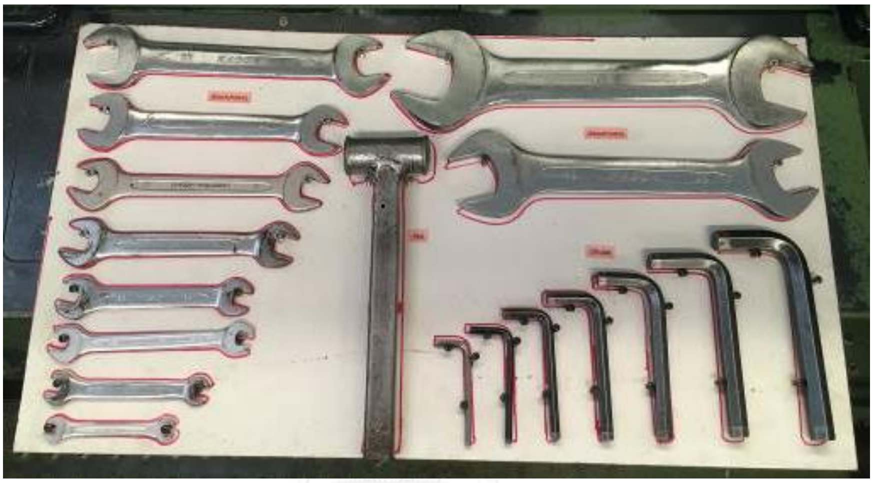


Figure 65: shadow board for bolt forming setup operation

Figure 66: shadow board for bolt forming setup operation

3.) Shine

The third action was tidying up the working area which referred to the shadow board and overall bolt forming area.

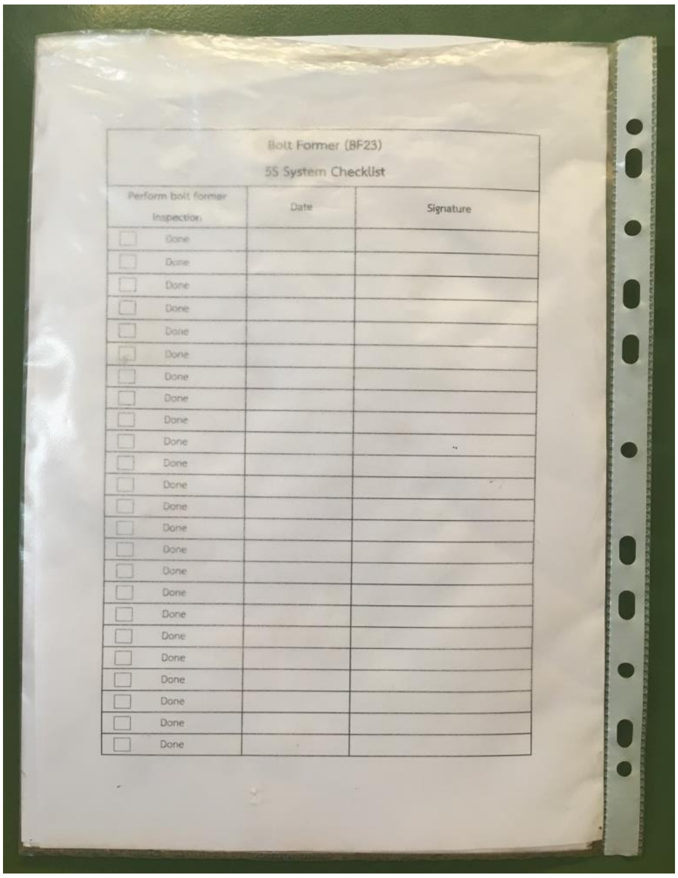
Figure 67: Shadow board on bolt former’s tool shelf

Figure 68: Setup operation area on bolt former

4.) Standardize

As sort, set in order and shine had been successfully implemented on bolt former BF 23, the company was agreed to implement the same concept to other bolt formers.

As mentioned in Methodology, a simple check sheet was developed to ensure the good work of 5S system as shown in Figure 69.



Bolt Former (BF23)

5S System Checklist

Perform bolt former inspection	Date	Signature
☐ Done		
☐ Done		
☐ Done		
☐ Done		
☐ Done		
☐ Done		
☐ Done		
☐ Done		
☐ Done		
☐ Done		
☐ Done		
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☐ Done		
☐ Done		
☐ Done		

Figure 69: 5S check sheet on bolt former BF23

This check sheet required operator to take care of bolt former cleanliness and investigate abnormalities on daily basis. Since it would only take few minutes to tidy up the working area and sign the checklist once finished, operators were willing to implement the improvement.

5.) Sustain

In order to continue the improvement in the future, all related parties including management, lead operator and operators, must be committed. Due to limited time frame of this research, results of sustainability could not be shown. Therefore, author would give recommendations to sustain the improvement.

a) Weekly audits by lead operator should be performed to evaluate the working area and ensure that operators take care of their working area which included signing the checklist. The only caution was to ensure that the purpose of audits was not to find mistakes of operators but to enhance the improvement.

b) Reward and recognition for good housekeeping program is annunciate monthly. The company should make sure that recognition for operator must be a big deal by supporting and congratulating for the job well done. However, as discussed with Production manager that the company did not want to give regular rewards to employees on good housekeeping, reward would only be given to the best performed operator annually.

External Setup Improvement

Spaghetti diagram for external setup

Same as internal setup, spaghetti diagram for external setup was drawn consisting of workplace layout and necessary details. The layout was drawn similar to scale and travel distance was identified using mobile application.

The spaghetti diagram for operator travel paths during current external setup are shown in Figure 70. The information of operator travel paths including travel details and travel distances are shown in Table 18.

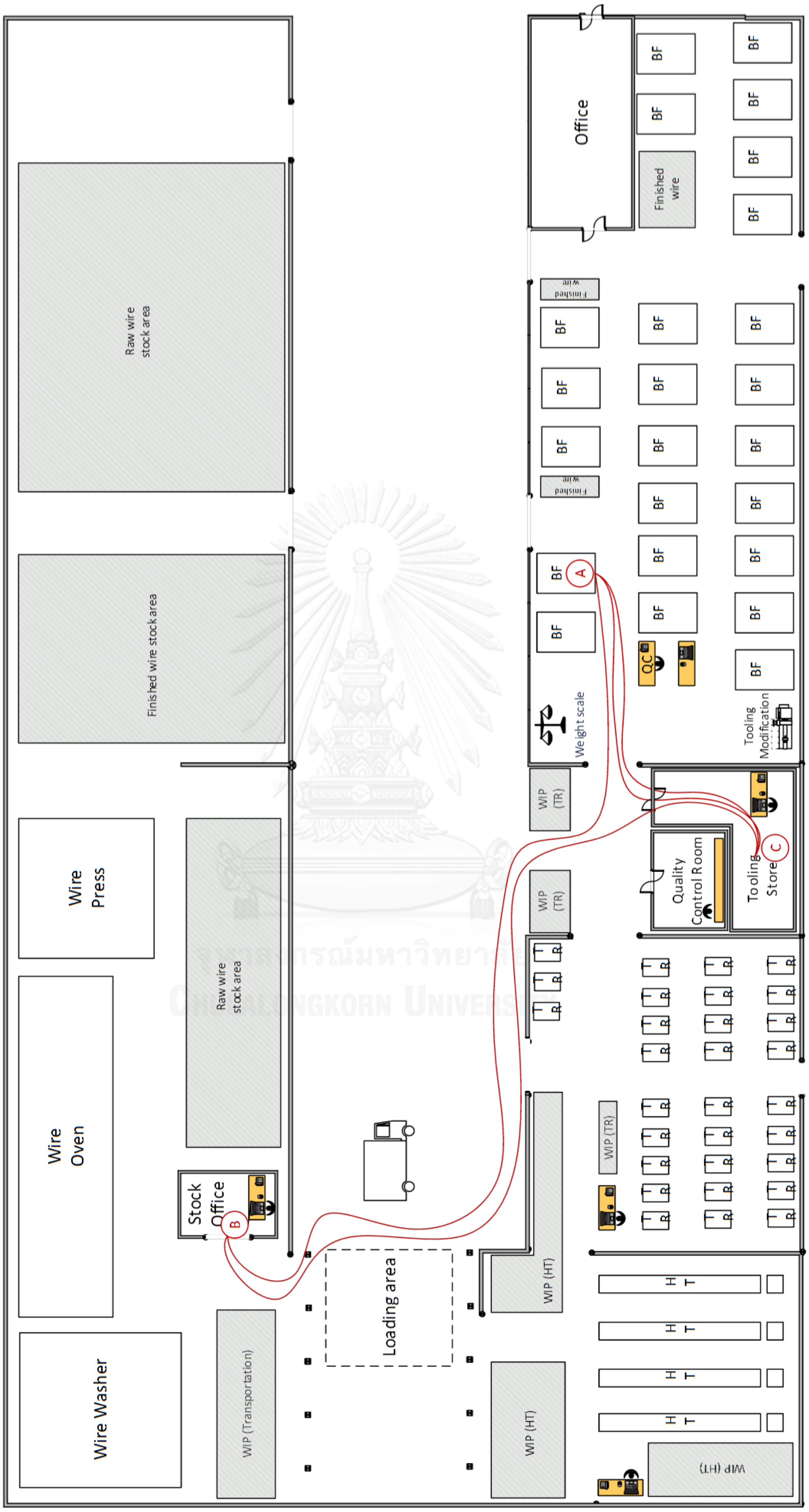


Figure 70: Spaghetti diagram for current external setup

Table 18: Current external setup travel summary

Route	From/To	Activity	Distance (m)
1	A/B	Request finished wire	60
2	B/C	Prepare toolings	40
3	C/A	Walk back to bolt former to start setup operation	20
4	A/C	Return dismantled toolings once setup operation is finished	20
Total distance			140

There were four routes for current external setup with total distance of 140 meters. However, finished wire preparation route 1 could be reduced. Operator could walk to the nearest phone at QC work station (10 meters) to call wire department and request finished wire for operation, instead of walking to wire department (60 meters). Wire department was able to know the type and size of finished wire that each production required by searching for Production order in company system. All operator had to do was informed wire personnel the Production order number for upcoming production. Consequently, route 2 travel path from wire department to tooling store (from B to C) could also be reduced. The improved spaghetti diagram and travel summary are shown in Figure 71 and Table 19, respectively.

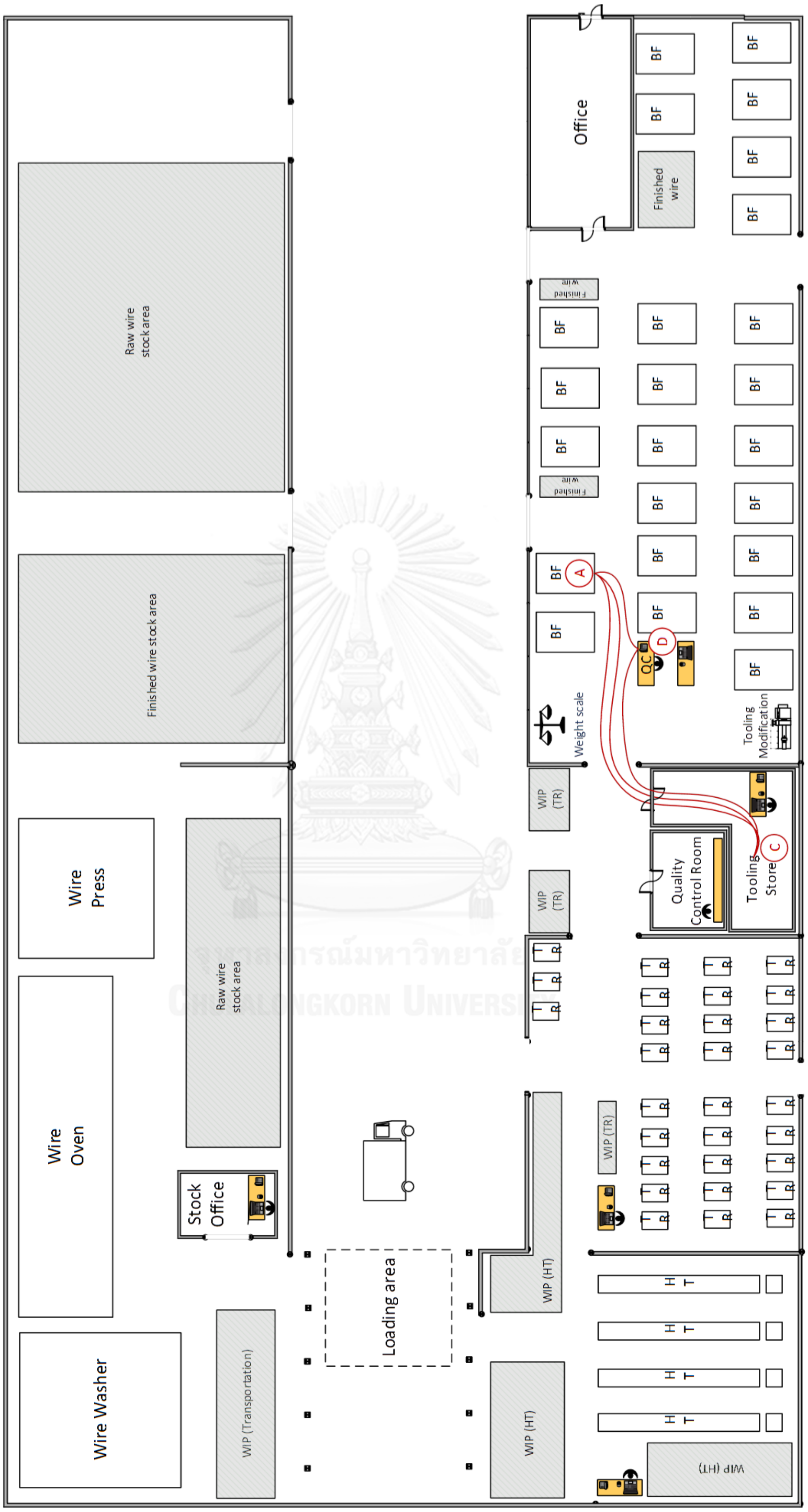


Figure 71: Improved spaghetti diagram for external setup

Table 19: Improved external setup travel summary

Route	From/To	Activity	Distance (m)
1	A/D	Request finished wire	10
2	D/C	Prepare toolings	10
3	C/A	Walk back to bolt former to start setup operation	20
4	A/C	Return dismantled toolings once setup operation is finished	20
Total distance			60

After improvement, travel distance was able to reduce from 140 meters to 60 meters.

5S System for external setup

As mentioned in 5S Methodology in Chapter 3, that by improving finished wire by 5S system would not directly help with setup time reduction and improving tooling with 5S system would take more than time frame of this research. Therefore, 5S system would not be implemented on external setup.

However, author would like to recommend the tooling store improvement as the future improvement projects. With more than 50,000 pieces of toolings, the company was unable to keep track on the usage of toolings. Every tooling had limited service life base on how many times it was used in production. As one of the problems arose from lead operator that sometimes operator picked up an expired tooling, leading to prolong setup operation since the tooling was not producing product properly and new tooling must be picked up during internal setup activities. A database or system should be created to keep track on the usage of every tooling. This would help identify and remove expired toolings from the store.

Figure 72: Tooling store department

5.2 Improvement implementation

5.2.1 Preparation for implementation

This research had categorized, rearranged and implemented parallel operation for all bolt forming setup activities in order to achieve minimum setup time. All improvements were prepared and two operators were trained to follow the improved setup operation procedure as shown in Table 20. Total of three improved setup operation for data collection were performed as same as the current setup operation in order to ensure the normal setup time. Two cameramen were also arranged to capture video of both operators.

Table 20: Improved bolt forming setup operation for implementation

Operator A			Operator B		
No.	Activity	Setup type	No.	Activity	Setup type
1A	Prepare finished wire	External			
2A	Prepare and assemble dies and punches	External			
3A	Stop the machine once previous production is finished	Internal	1B	Weigh previous products	External
4A	Dismount the previous dies and punches out of machine	Internal	2B	Fill in Self-Inspection Check Sheet and Production Report for previous products	External
5A	Dismount the previous wire toolings out of machine	Internal	3B	Dismount the previous feeding rollers out of machine	Internal
6A	Dismount the previous grippers out of machine	Internal	4B	Mount new feeding rollers onto machine	Internal
7A	Mount new wire toolings onto machine	Internal	5B	Connect finished wire onto machine	Internal
8A	Mount new grippers onto machine	Internal	6B	Clean up the previous dies and punches	External
9A	Mount new dies and punches onto machine	Internal	7B	Return dismantled dies and punches to the storage	External
10A	Trial runs and adjustment of dies, punches and wire toolings	Internal			
11A	Test run machine at production speed	Internal			
12A	Inspect the finished products by Quality Control personnel	Internal			
13A	Fill in First Piece Inspection Check Sheet	External			

Operator A was responsible for main setup operation on machine platform as discussed SMED stage 3 improvement, with total of 13 setup activities. Setup activities of operator A were quite straight forward, activities between stopping machine from previous production and restarting machine for next production were minimized to only necessary activities.

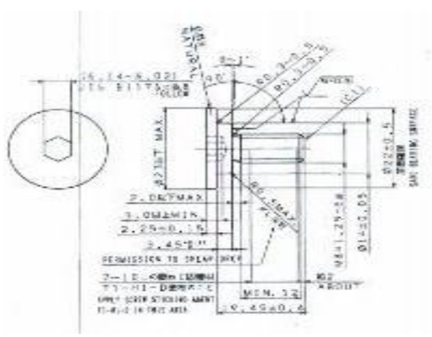
While operator B was responsible for finished wire related activities and other external activities to help reduce operator A's activities such as weigh previous products and fill in previous finishing forms. Total of 7 setup activities of operator B started once operator A had stopped the machine (3A). As shown in Table 20, operator B's activities started with finishing up previous production even though they were external setups, as the company would like to close previous production and send them to the next process as soon as possible. The only important concern for operator B was the internal activities (3B – 5B) must be done before operator A started doing trial runs and adjustment (10A). However, as calculated from current setup operation duration of those activities, it should not be a problem.

Furthermore, as immediate solution to prevent rework activities as mentioned during five whys technique, a quality control personnel was invited to explain what QC was looking for in a finished product and common mistakes about product A.

Documents for setup operation including revised Production order and Step adjustment guideline were prepared for implementation. Production order with target value and tooling list are shown in figure below.

Production Order

SEMI FG (Bolt former)



WO160905897

Reference Production	WO160905897	Drawing No.	DWG NO 15-
Product Code	*Confidential		
Product Name	Product A		
Customer	*Confidential		
Date	24/09/2016	Finish Date	24/09/2016
Delivery Date	*Confidential		
Production Amount	*Confidential kg	*Confidential	piece

Process No.	Process Code	Process Name	Model	Machine	
1	*Confidential	Bolt forming	*Confidential	BF23	
	Wire Production	Name	Amount	Unit	Warehouse	Location

Wire Production	Name	Amount	Unit	Warehouse	Location
W0970S435R4	Finished Wire Rod SCM435 09.70 (R4)	100	kg	WH-08B	B

No.	Description	Note
1	Body width (ความโตช่วงรีดเกลียว)	7.05 - 7.09 [Target 7.07]
2	Body length (ความยาวช่วงรีดเกลียว)	15.70 - 15.95 [Target 15.70]
3	Total bolt length (ความยาวช่วงรีดเกลียว+วัดรวมบ่า)	23.50 +/- 0.2 [Target 23.50]
4	Head thickness (ความหนาหัว)	2.10 - 2.40 [Target 2.25]
5	Shoulder width (ความโตบ่า)	13.95 - 14.03 [Target 13.95]
6	Head width (ความโตหัว)	22.50 - 23.00 [Target 22.90]
	FIBER FLOW	FLOW continuous

Note: Product picture is blurred for confidentail details

Remarks	Maker	Checker

Figure 73: Production order of product A (page 1 of 2)

Production Order

SEMI FG (Bolt former)

WO160905897

No.	Item number	Tooling name	Category	Location
1	TE15-1571-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.1 C006491021	Die	TE store
2	TE15-1572-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.2 C006491021	Die	TE store
3	TE15-1573-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.3 C006491021	Die	TE store
4	TE15-1574-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.4 C006491021	Die	TE store
5	TE15-1575-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.2 C006491021	Punch	TE store
6	TE15-1576-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.3 C006491021	Punch	TE store
7	TE15-1577-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.4 C006491021	Punch	TE store
8	TE15-1578-01	SECOND PUNCH TIN M8x1.25x19.45 P-SK(SP) 30MM. C006491	Punch	TE store
9	TE12-1433-01	KO. PIN No.1/6.98X140	Die	TE store
10	TE12-1434-01	KO. PIN No.2/6.98X140	Die	TE store
11	TE12-1435-01	KO. PIN No.3/6.98X140	Die	TE store
12	TE12-1436-01	KO. PIN No.4/5.35X140	Die	TE store
13	TE12-1437-01	KO. PIN Spacer No.1/7.02X12	Die	TE store
14	TE12-1438-01	KO. PIN Spacer No.2/7.02X12	Die	TE store
15	TE12-1439-01	KO. PIN Spacer No.3/7.02X12	Die	TE store
16	TE12-1440-01	KO. PIN Spacer No.4/5.40X12	Die	TE store
17	TE14-0081-01	PUNCH PIN No.2/9.75X65	Punch	TE store
18	TE14-0095-01	PUNCH CASE No.1	Punch	TE store
19	TE14-0098-01	PUNCH Spacer No.1/25.8X55	Punch	TE store
20	TE14-0099-01	PUNCH Spacer No.2/25.8X70	Punch	TE store
21	TE20-1100-01	Cutter 9.85X15	Wire	TE store
22	TE20-1104-01	Cutter(FIXED) 9.85X66	Wire	TE store
23	-	Wire Roller 9.80	Feeding roller	TE store

Remarks	Maker	Checker

Figure 74: Production order of product A (page 2 of 2)

Step adjustment guideline of product A contained indicating adjustment scale of wire length and dies adjustment, and step by step product output measurement. Moreover, suitable measurement tools for each part of product are also indicated as shown in Figure 75.

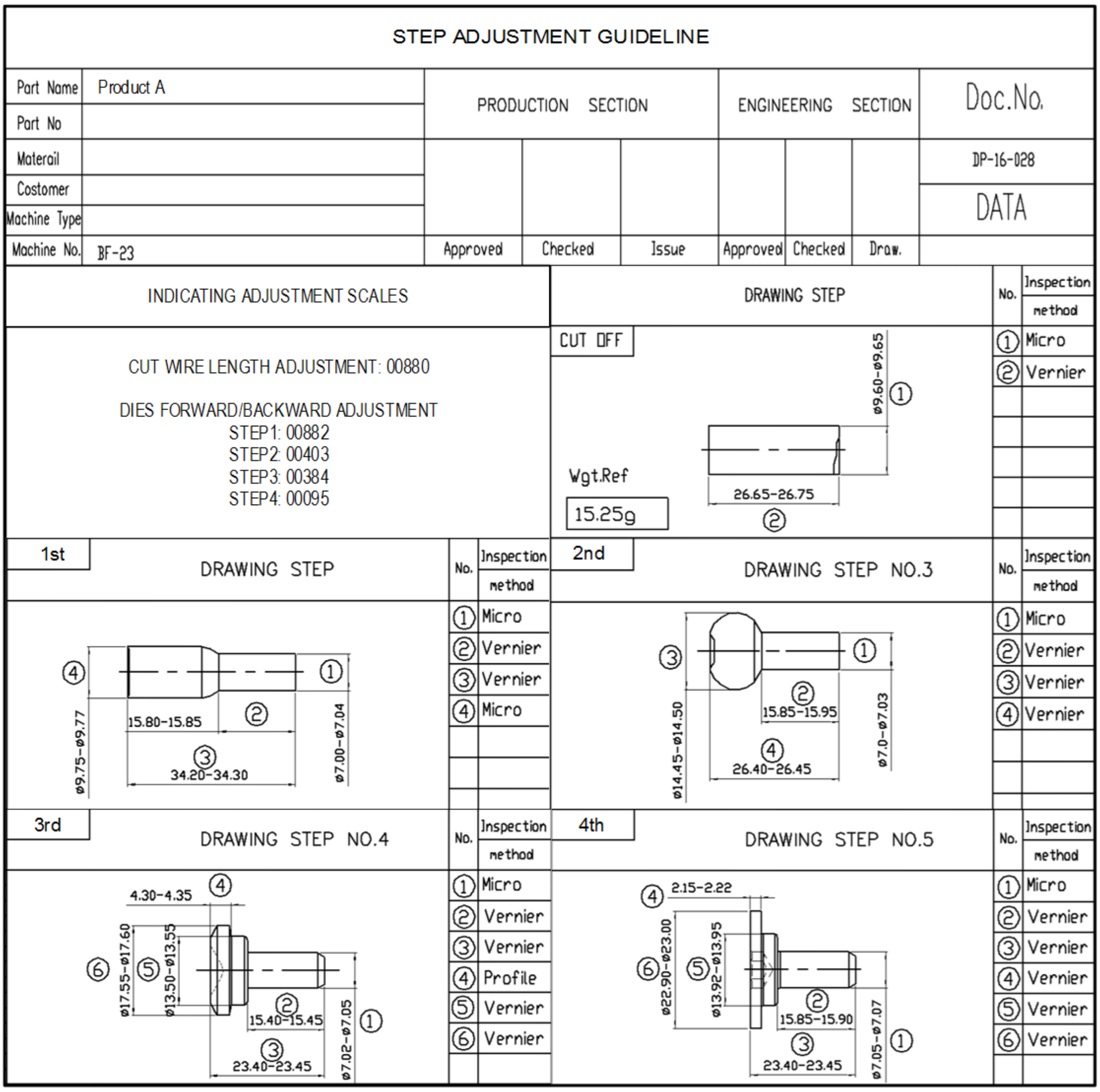


Figure 75: Step adjustment guideline for product A

5.2.2 Improvement implementation

The following pictures were snapshots from video recording which illustrated setup activities of setup operator A and operator B, respectively. However, some activity steps may have more than one picture to show the details of that step.

<u>**Operator A**</u>

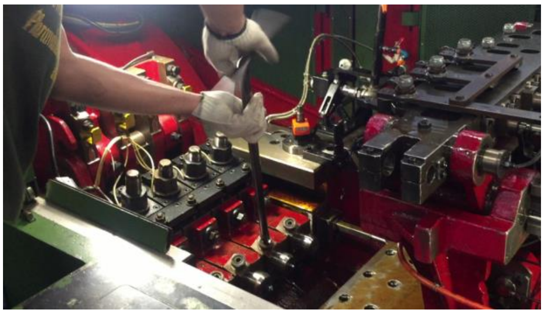
Figure 76: Step 1A Prepare finished wire

Instead of walking to wire department, operator called wire personnel and informed Production order number to request finished wire.

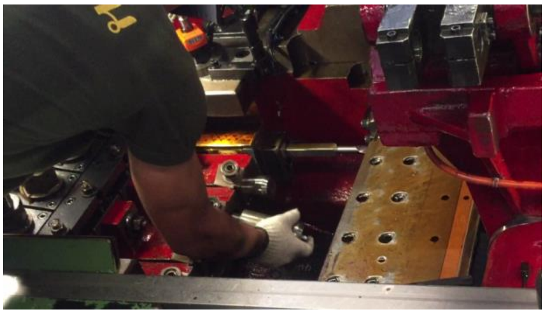
Figure 77: Step 2A Prepare and assemble dies and punches

Operator used complete tooling list in Production order to prepare toolings from tooling store and assembled as an external setup activity. All toolings were then ready to be put into the machine.

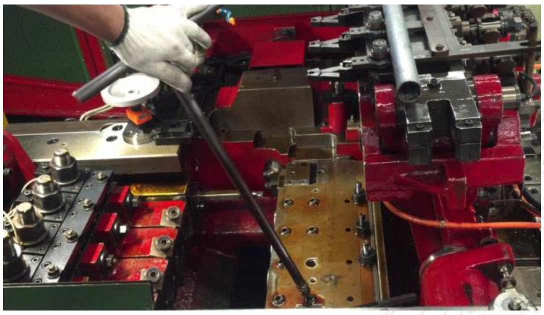
Figure 78: Step 3A Stop the machine once previous production is finished



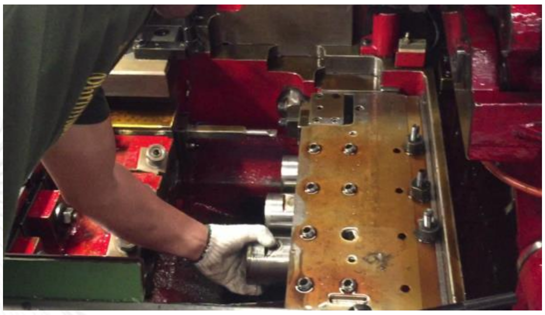
i) Loosen nuts on punch side



ii) Remove punches out of machine



iii) Loosen nuts on die side



iv) Remove dies out of machine

Figure 79: Step 4A Dismount the previous dies and punches out of machine

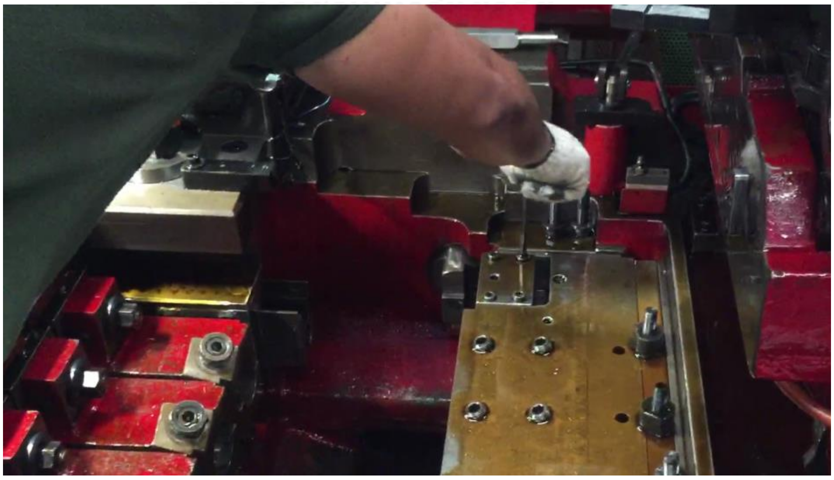


Figure 80: Step 5A Dismount the previous wire toolings out of machine

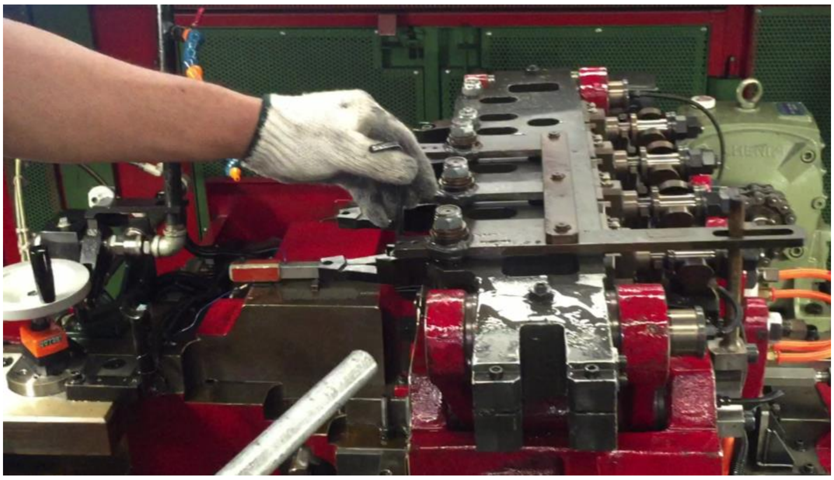


Figure 81: Step 6A Dismount the previous grippers out of machine

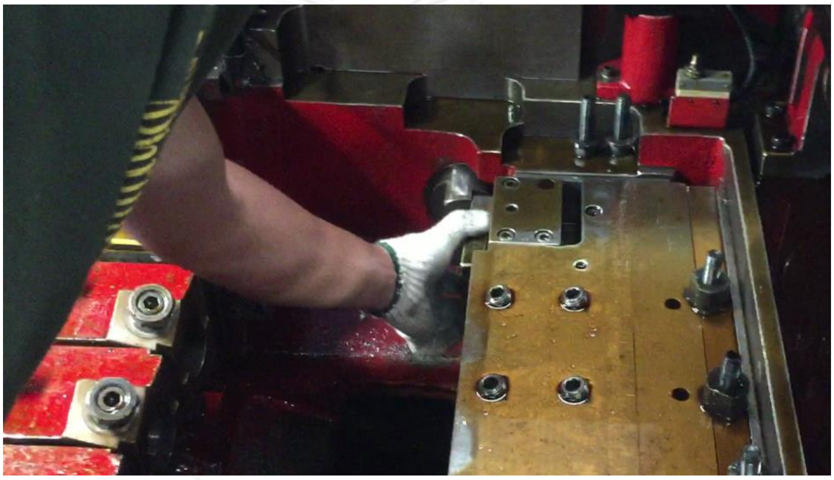


Figure 82: Step 7A Mount new wire toolings onto machine

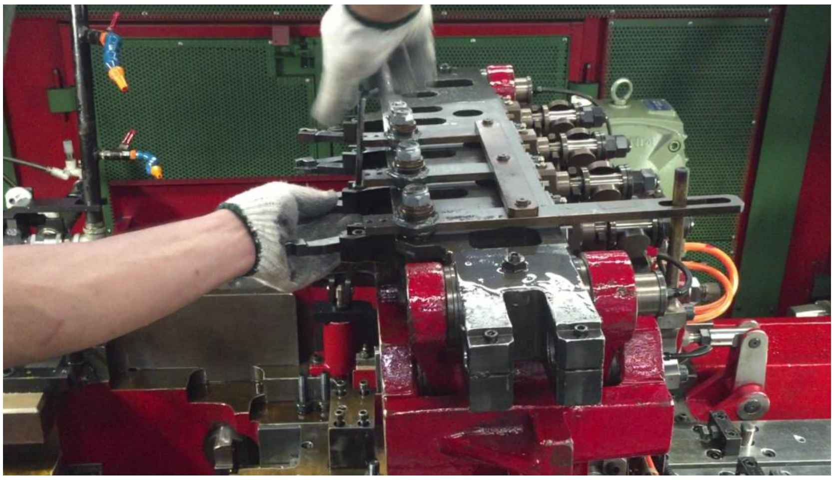
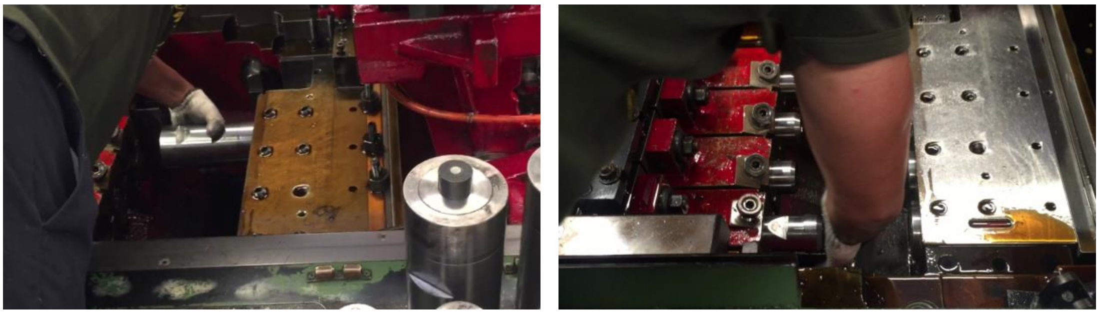


Figure 83: Step 8A Mount new grippers onto machine



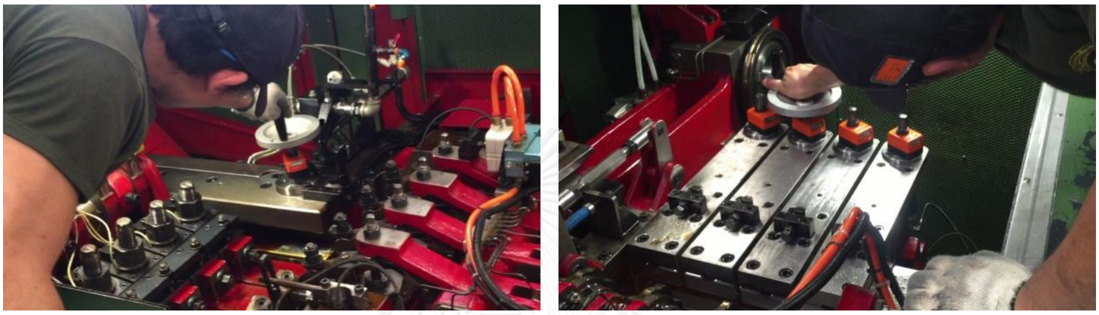
i) Mount new dies onto machine ii) Mount new punches onto machine

Figure 84: Step 9A Mount new punches and dies onto machine

Figure 85: Quickly locate necessary tools on shadow board

During dismount/mount and adjustment of all toolings, operator A was able to locate required tools quickly on shadow board which save unnecessary time looking for tools in toolboxes.

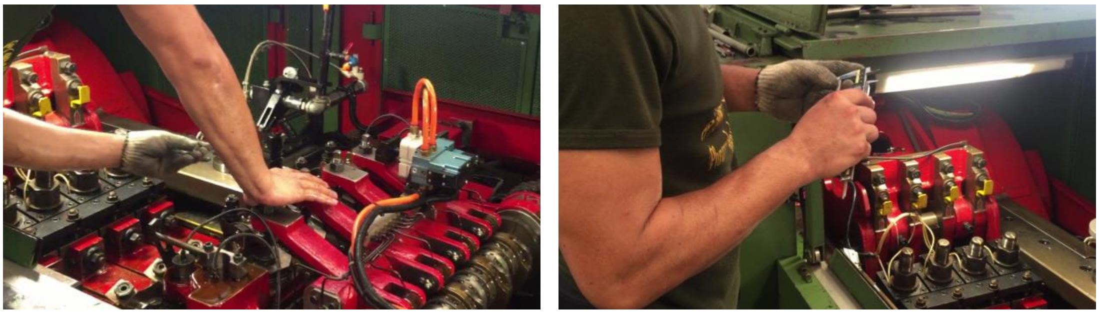
i) Review improved Production order and Step Adjustment Guideline



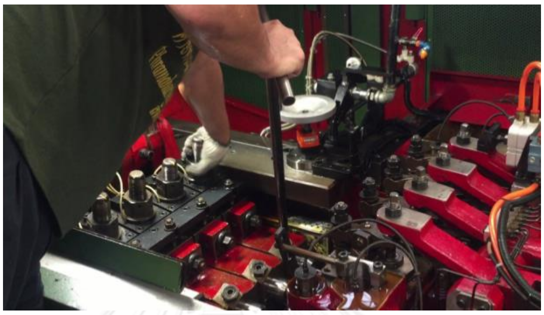
ii) Make adjustment on wire length (left) and die side (right)

Operator A was able to turn wire length and dies forward/backward adjustment scales to the value indicating in Setup adjustment guideline. This reduced number of adjustment factors. Therefore, the attention for trial runs and adjustment activity was then focused only on the adjustment of punch side.

iii) Jog machine



iv) Pick up product from gripper and check sizes of product using measuring tools



v) Make adjustment only on punch side

Figure 86: Step 10A Trial runs and adjustment

As Step adjustment guideline provided size and dimension in each transformation step, operator was able to make adjustment and compare product step by step from step 1 to 4 in sequence. This not only eliminated the back and forth adjustment, but it also reduced number of trial runs and adjustment cycle comparing to the current setup operation.

Figure 87: Step 11A Test run machine at production speed

Test run was a way to ensure that once machine was running at production speed, products' sizes were not deviated from the products of trial runs and adjustment. In order to reduce setup time, operator was allowed to test run only 50-100 pieces of products which was an adequate amount to spot the deviations, if any.

Figure 88: Step 12A Inspect the finished products by Quality Control personnel

Quality control personnel approved products inspection without any rework activities required as operator knew how to check the quality of products according to the QC training and required target value stated on Production order. Therefore, operator was able to start the next production as soon as the first inspection was approved.

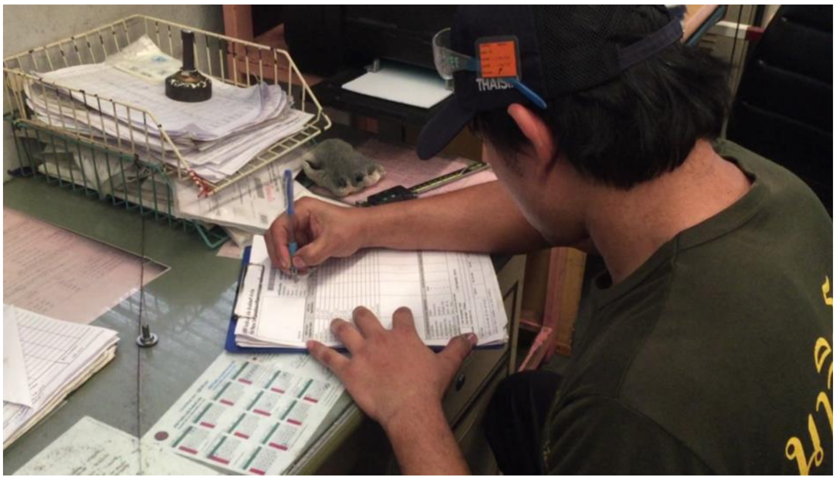


Figure 89: Step 13A Fill in First Piece Inspection Check Sheet

The last setup activity for operation A, fill in first piece inspection check sheet was rearranged to be an external setup after the production had started to reduce setup time.

<u>Operator B</u>

Figure 90: Step 1B Weigh previous products

Operator B had hooked digital weight scale to overhead crane as an external setup. Therefore, once the last piece of previous production fell into the bin, he was able to hook up, weigh and transfer finished product bin to the waiting area right away.

i) Fill in Self-Inspection Check Sheet　　ii) Fill in Production Report in computer

Figure 91: Step 2B Fill in Self-Inspection Check Sheet and Production Report for previous product

Figure 92: Step 3B Dismount the previous feeding rollers out of machine

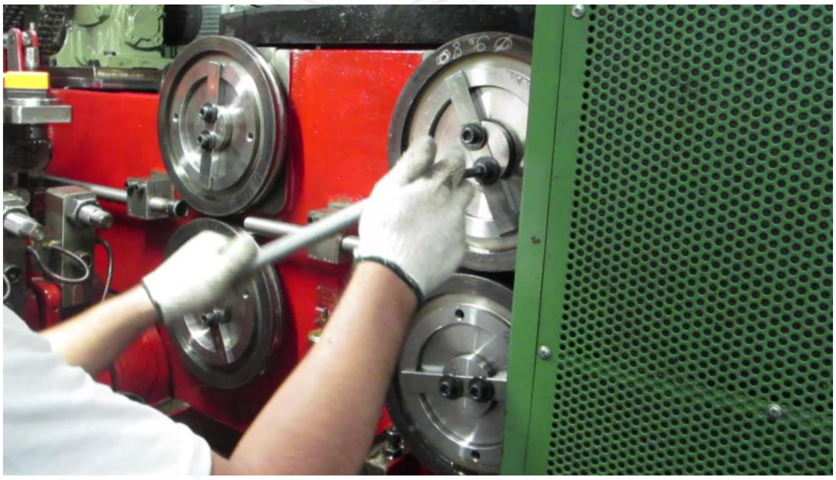


Figure 93: Step 4B Mount new feeding rollers onto machine

Figure 94: Step 5B Connect finished wire onto machine

Operator B was able to connected finished wire onto bolt former before operator A started on trial runs and adjustment, which was the only timeline concern for operator B. Operator A was immediately informed by operator B as soon as finished wire was connected.

Figure 95: Step 6B Clean up the previous dies and punches

Figure 96: Step 7B Return dismantled dies and punches to the storage

After the implementations of both operators were completed, videos were reviewed and analyzed. The sub-activities details of full improved implementation for all three time data collection are shown in Appendix B2. The longest setup time among the three collected data was selected to represent the worst case scenario as same as for current setup operation. The activity lists of operator A and operator B are shown in Table 21 and Table 22, respectively.

Table 21: Improved setup operation activity list of operator A

Step	Activity (Operator A)	Duration (h:mm:ss)	Setup type
1A	Prepare finished wire	0:01:48	External
2A	Prepare and assemble dies and punches	0:28:13	External
3A	Stop the machine once previous production is finished	0:00:51	Internal
4A	Dismount the previous dies and punches out of machine	0:06:45	Internal
5A	Dismount the previous wire toolings out of machine	0:03:03	Internal
6A	Dismount the previous grippers out of machine	0:02:10	Internal
7A	Mount new wire toolings onto machine	0:06:14	Internal
8A	Mount new grippers onto machine	0:04:41	Internal
9A	Mount new dies and punches onto machine	0:14:56	Internal
10A	Trial runs and adjustment of dies, punches and wire toolings (the cycle was repeated 18 times) *Note 1	0:32:27	Internal
11A	Test run machine at production speed	0:02:00	Internal
12A	Inspect the finished products by Quality Control personnel	0:01:42	Internal
13A	Fill in First Piece Inspection Check Sheet	0:11:36	External

Note 1: Trial runs and adjustment consists of repeated activities as explained in detail in Appendix B3, Note 1.

Table 22: Improved setup operation activity list of operator B

Step	Activity (Operator B)	Duration (h:mm:ss)	Setup type
1B	Weigh previous products	0:02:32	External
2B	Fill in Self-Inspection Check Sheet and Production Report for previous products	0:07:54	External
3B	Dismount the previous feeding rollers out of machine	0:04:53	Internal
4B	Mount new feeding rollers onto machine	0:09:47	Internal
5B	Connect finished wire onto machine	0:12:30	Internal
6B	Clean up the previous dies and punches	0:21:09	External
7B	Return dismantled dies and punches to the storage	0:08:12	External

The overall improvement implementations were successfully performed including two operators working in parallel. Operator A had done total of 13 activities and operator B had done 7 activities. Operator B was able to finish the necessary activity for operator A continuity work (5B) before operator A started trial runs and adjustment (10A) as predicted. Operator B finished connecting finished wire onto machine (5B) at the time 37 minutes and 36 seconds, whereas operator A started trial runs and adjustment (10A) at the time 38 minutes and 40 seconds, which gave the time lapse of 1 minute and 4 seconds.

Since the lapse time was quite small, an alternative sequence for operator B was considered. In the case where operator A had to wait for operator B, external activities of operator B (1B and 2B) could be pushed down to be performed after internal activities were finished (3B through 5B). Even though this altered sequence was not preferred by the company, it ensured that operator A did not have to wait for operator B.

However, from three data collections from the improved setup operation, operator B was always finished connecting finished wire onto machine before operator A started trial runs and adjustment. Therefore, the mentioned concern was unlikely to happen.

Setup time summary of the improved implementation of both operators and both setup types are shown in Table 23. Since the setup time was defined by the internal setup time of operator A, the improved setup time result was 1 hour 14 minutes and 49 seconds. The detail of improved setup time is also drawn in Figure 97.

Table 23: Improved setup operation time summary

Detail Summary	Time (h:mm:ss)	
	Operator A	Operator B
Setup Time	1:14:49	0:27:10
External Setup Time	0:41:37	0:39:47

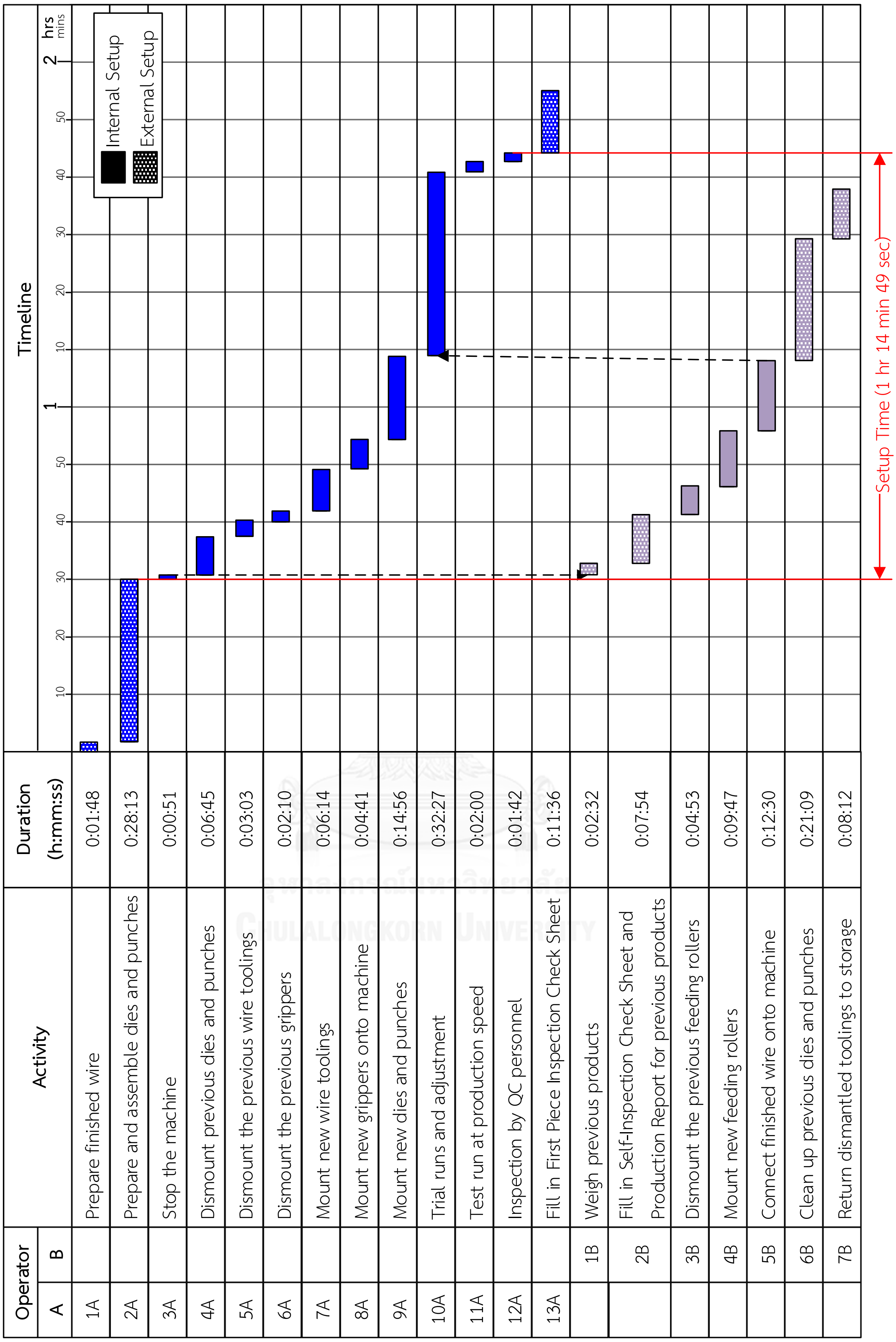


Figure 97: Improvement implementation setup time result

5.2.3 Post improvement implementation

After successful improvement implementation and result were achieved, standard operating procedure was created. As mentioned in one of Method problems in cause and effect diagram in section 3.3 Problem identification and analysis, that the company did not have standard operating procedure, which resulting in inconsistency performance depending on individual's experiences and skills.

Standard operating procedure (SOP) for bolt forming setup operation was a step by step working instruction that standardize the ways of doing setup operation as shown in Figure 98.

The SOP must be trained to all operators and used during introduction to bolt forming setup operation training for new operators, in order to create a common and complete understanding of the job. Moreover, SOP was also put on bolt former where setup operation took place as a reminder to help operators carry out the operation.

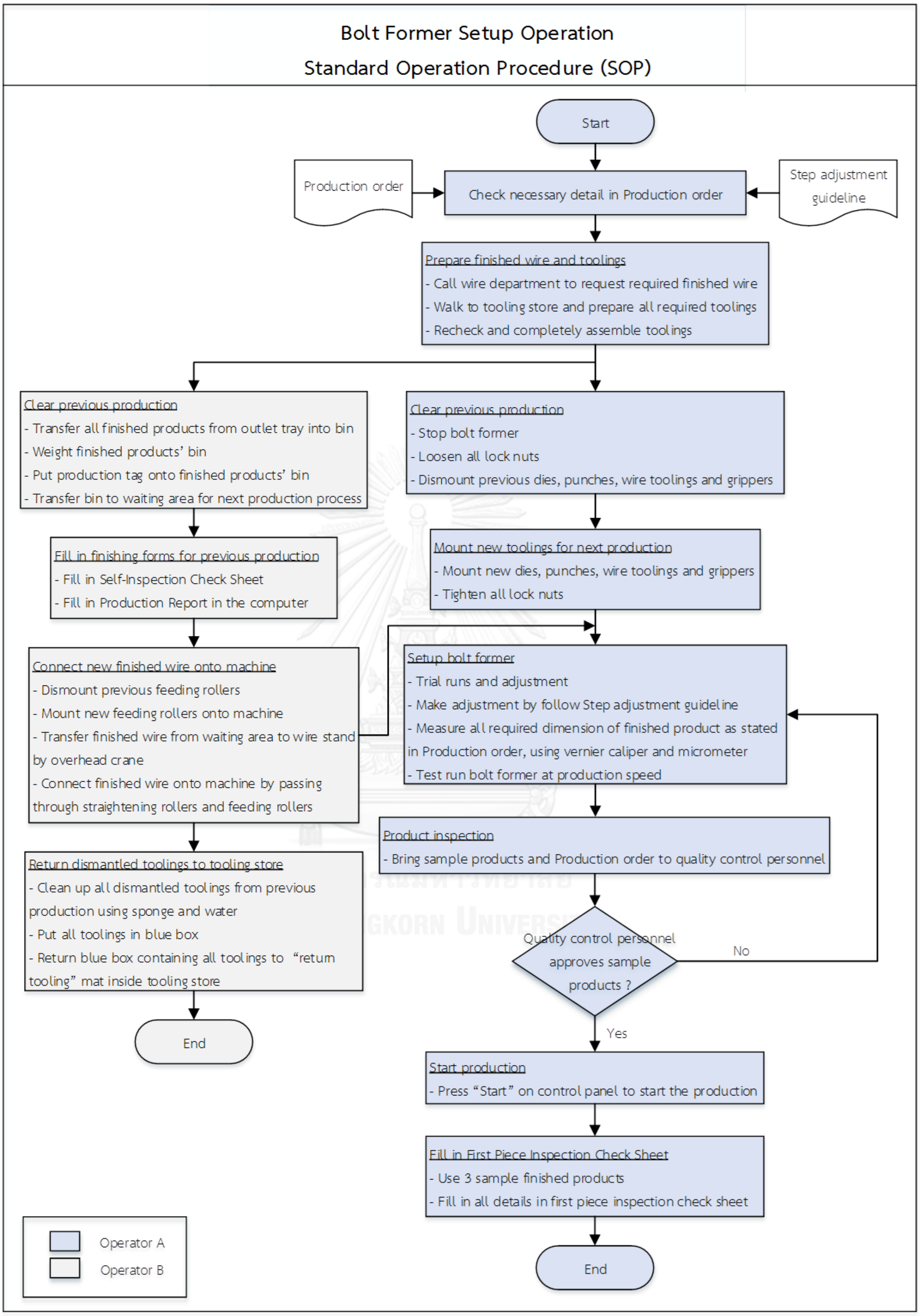


Figure 98: Standard operating procedure of bolt forming setup operation

5.3 Process improvement and implementation summary

According to improvement framework, detail of all improvements had been implemented in this chapter. The first step improvement, SMED setup time improvement illustrated all setup activities including internal and external setup. Current setup time was 4 hours and 9 minutes as stated in stage 0. The implementation of stage 1 to distinguish internal and external setup resulted in setup time reduction to 3 hours and 16 minutes theoretically. Stage 2 was unable to implement due to company's constraints. Parallel operation in stage 3 was able to reduce setup time to 2 hours and 48 minutes theoretically.

Refined setup time improvement, second step improvement implemented on Pareto and five whys analysis for internal setup. The research was able to identify root causes of three main activities for major time loss and find solutions for all three activities i.e. Step adjustment guideline development, completed tooling list and target values in Production order, and training programs. Spaghetti diagram was unable to reduce travel distance in internal setup, but able to reduce travel distance from 140 to 60 meters in external setup. The implementation of 5S system for internal setup was successfully created shadow board for tool usage efficiency of setup operation. On the other hand, 5S system was not able to implement in external setup due to research's limitation.

The implementation of improved setup operation had been performed using two operators with improvement setup procedure. The result also shown setup time was reduced to 1 hour and 14 minutes. And finally, standard operating procedure was created to help operators understand new ways to perform bolt forming setup operation.

Chapter 6 Result and Discussion

Results and discussion of bolt forming setup time improvement research has divided into three parts i.e. quantitative result, qualitative result and expected result. The quantitative result is the result and comparison that can be illustrated in numbers which consisting of setup time reduction, total setup time reduction, trial runs and adjustment reduction, and increase overall equipment effectiveness. Qualitative result is expressed in the interviews of operators. As this research's improvements have changed their daily operation, it is necessary to listen and analyze their opinion and recommendation. Finally, expected result part mentions the potential benefits that are caused by bolt forming setup time improvement.

6.1 Quantitative Result and Discussion

6.1.1 Setup time reduction

The result of SMED and refined improved implementation of bolt forming setup operation was satisfied. As shown in Table 24, setup time was able to reduce from 4 hours 9 minutes and 20 seconds to 1 hour 14 minutes and 49 seconds, with setup time reduction of 2 hour 54 minutes and 34 seconds. Total percentage reduction was 70 percent as shown in Figure 99. This result had exceeded company's expectation to reduce setup time to 2 hours.

Table 24: Setup time reduction

Detail Summary	Time (h:mm:ss)		
	Before	After	Reduction
Setup Time	4:09:20	1:14:49	- (2:54:31)

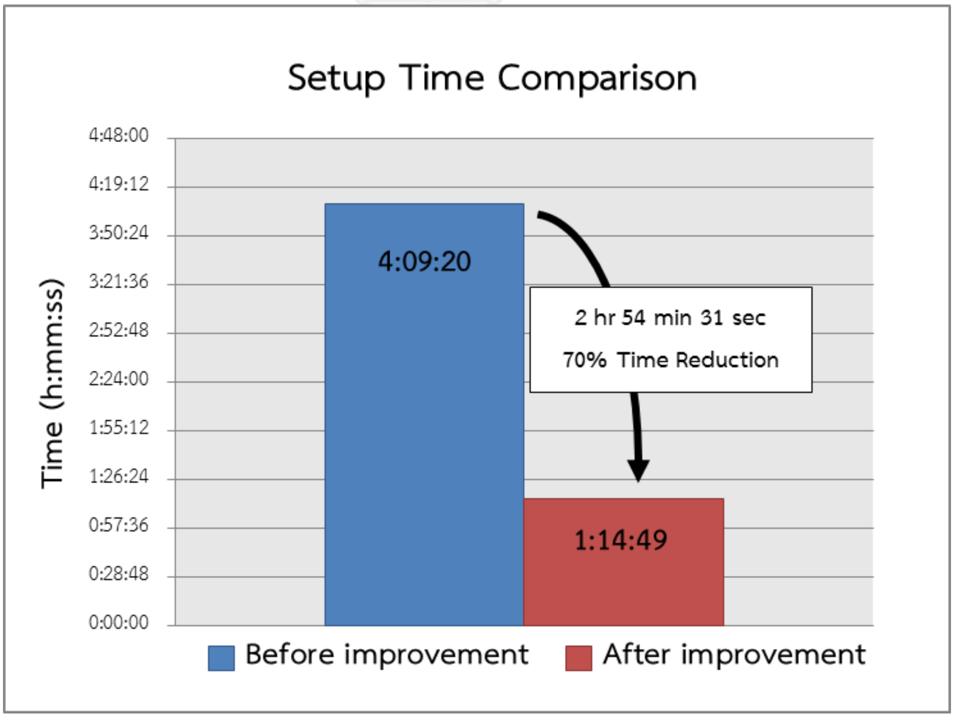


Figure 99: The comparison of setup time before and after improvement

The exceed expectation result of setup time reduction was due to two-step improvement of SMED setup time improvement and refined setup time improvement, which emphasized on the improvement of both process and people. This research captured all details that comprised to bolt forming setup operation. This research involved all related personnel from management team to shop floor operator to participate in the improvements, which allowed problems to be analyzed in different point of views. The combination of different perspectives was helpful to improvement ideas, leading to the great solutions and results.

The improvement of setup operation process by **rearranging sequence** of setup activities and implementing **parallel operation** indicated the obvious reduction in setup time. Since the internal setup and external setup were clearly distinguished and setup sequences were reasonably and practically reordered. For parallel operation, two operators had been assigned to work together which clearly reduce setup time without adding new cost of hiring new ones. This also helped utilized company's resources more effectively. However, effective communication must be practiced. By completing all inputs in **Production order** including **tooling list** and **target value** reduced chances of unnecessary rework. The development of **Step adjustment guideline** made the most difficult and time consuming activity of setup operation easier by guiding operator on trial runs and adjustment. And finally, wire department **travel distance reduction, weight scale replacement** and **shadow board** allowed operators to work more conveniently.

Training operators were parts of people improvement. Operators learned the effective ways to do setup operation and how to investigate the finished products. The result of training in this implementation eliminated all rework activities that accounted for the third biggest time loss during current operation.

6.1.2 Total Setup time reduction

The total setup time referred to overall time spent doing setup operation including both internal and external setup activities. As shown in Table 25, total setup time was reduced from 4 hours 51 minutes and 35 seconds with one operator to the combine time of 3 hours 3 minutes and 23 seconds for two operators after the implementation. Total reduction was 1 hour 48 minutes and 12 seconds or 37 percent. The reduction of total setup time can be considered as the reduction of man-hour usage for setup operation.

Table 25: Total setup time reduction

Detail Summary	Time (h:mm:ss)			
	Before	After		Reduction
		Operator A	Operator B	
Setup Time	4:09:20	1:14:49	0:27:10	
External Setup Time	0:42:15	0:41:37	0:39:47	
Total Setup Time (internal & external setup)	**4:51:35**	**3:03:23**		**- (1:48:12)**

Even though, the setup time reduction was resulted from two steps improvement of SMED and refined setup time improvement as mentioned in section 6.1.1. However, total setup time reduction was achieved only through process improvements of refined setup time improvement. As in SMED setup time improvement, setup time was reduced due to distinguishing, rearranging activities, and applying parallel operation. None the less, total setup time was the combination of all internal and external setup activities and was not reduced from the mentioned improvement techniques from traditional SMED. Therefore, it was concluded that the reason for total setup time reduction was due to only improvement step 2, refined setup time improvement.

6.1.3 Trial runs and adjustment reduction

As mentioned that trial runs and adjustment was a cycle consisted of three main activities i.e. jog machine, pick up product from gripper to measure using vernier caliper and micrometer, and make further adjustment. In the current setup operation, this cycle was repeated for 32 times with the duration of 49 minutes and 45 seconds. After the improvement emphasizing on the development of Step adjustment guideline, the cycle was reduced to 18 times with duration of 32 minutes 27 seconds as shown in Table 26.

Table 26: Trial runs and adjustment reduction

Trial runs and adjustment detail	Current setup operation	Improved setup operation	Reduction
Repeated cycle (no. of cycle)	32	18	- (14)
Duration (h:mm:ss)	0:49:45	0:32:27	- (0:17:18)

Not only the improvement reduced number of cycle and duration, operator was able to perform this activity in more orderly and systematic ways. Even though trial runs and adjustment was still the most time consuming activity, the time was reduced by 17 minutes and 18 seconds.

6.1.4 Increase overall equipment effectiveness

According to value stream mapping from chapter 1, the ineffectiveness of bolt former was one of the problems that led to the improvement of bolt forming setup time. The performance of bolt former was measured by overall equipment effectiveness (OEE) with only 82% uptime. As OEE was calculated based on three factors i.e. availability (A), performance (P), and quality (Q), the reason for the ineffectiveness was mainly due to long setup time of 4 hours which affected the availability factor.

After the improvement, bolt former setup time was reduced to 1 hour and 14 minutes. The availability factor (A) increased due to setup time reduction with the same machine performance (P) and quality of product (Q), overall equipment effectiveness had increased to 86% as shown in Table 27.

Table 27: Increase in overall equipment effectiveness

Description	Current setup operation	Improved setup operation	Percentage Increase
Overall equipment effectiveness	82%	86%	+ 4%

6.2 Qualitative Result and Discussion

Apart from setup time reduction results, this research concerned about what operators thought about the improvement. By interviewing the operators, the unquantified results can be collected which was also one of the important aspects of setup time improvement. Moreover, the recommendations from operators can be given for further improvement actions. The operators' interview on each improvement elements are summarized below.

6.2.1 SMED Setup Time Improvement

Distinguish and re-sequence setup activities

New sequences of setup activities were theoretically reasonable and able to reduce setup time. However, it would take some times for all operators to get used to new sequences.

Parallel operation

It was more challenging to work in pairs instead of working alone. Two operators had to be responsible and concerned about each other timeline and safety. However, it was a good improvement for setup time. In each setup operation, each operator had less setup activities which means each operator did not have to work as hard and as long as before.

6.2.2 Refine Setup Time Improvement

Revised Production order with complete tooling list and target value

The complete tooling list in Production order was significantly important and useful, especially to new operators. Since before the improvement, operators had to figure out themselves the required toolings for each production since each tooling made different shape of product. Often that lead operator had to advise and help new operators in this activity which was not ideal. The complete tooling list was able to solve this problem and every operator would be able to prepare toolings by themselves.

Target value was also helpful during setup adjustment since operators were able to know the exact value to adjust to. Before the improvement, range of acceptable values were given in Production order but quality control would ask to readjust to a specific value to prepare for the next production process. The target value would eliminate many of reworks including trial runs and adjustment.

Step adjustment guideline

It was an interesting improvement to help with trial runs and adjustment. Even though the scale values were not the exact values for setup operation every time because of different finished wire and toolings, but it was a good guideline to help reduce huge amount of time from adjustment.

Training

The trainings for new entrants should be taken place, but operators were skeptical about lunch and learn sessions and how long it was going to last. However, operators were glad to learn few tips from quality control personnel and lead operators to help improve their setup skills.

Preparation of finished wire by phone

Operators were pleased with this improvement because of shorter travel distance. The only concern was to get wire department to answer the phone and have effective communication.

5S implementation (shadow board)

5S implementation required operators to clean and look after bolt former working area which meant more responsibility for operators. However, operators were on board with this improvement as it would be hard work the first time to clean up current bolt former, but later times would be easy to maintain. Moreover, shadow board was useful during setup operation and reduced time finding required tools.

Digital weight Scale

The digital weight scale gave higher accuracy and reduced time to balance dumbbells. However, the location of digital weight scale while not in used shall be advised in order for all operators to be able to find it.

The overall feedbacks mentioned the appreciation that company finally tried to study and improve the setup operation. Many problems were there for a long time that it became normal routine. Not only this improvement research reduced bolt forming setup time which had many benefits for production process, but it also helped simplify and improve operators' setup operation.

6.3 Expected Result and Discussion

After successfully reduced bolt forming process setup time, the company can expect other potential benefits in the future. The company is able to improve and better control production flow to gain competitive advantages. With 70 percent reduction in setup time, the company can avoid overproduction to compensate with long setup time and produce in smaller batch size. As a result, the company is expected to reduce waiting time and inventory level in production process including at Heat treatment process, as ones of the problems found in current value stream mapping. Furthermore, the company is able to produce more various types of products which open new opportunities in the market from existing and new customers.

Chapter 7 Conclusion and Recommendation

7.1 Conclusion

In order to improve responsiveness and flexibility of production process, this research began by drawing value stream mapping to identify waste in production process. Three identified problems of ineffectiveness in bolt forming, long waiting time and high level of inventory at Heat Treatment process, led to necessity for improving setup time of bolt forming process.

Problem analysis for bolt forming setup operation was proceeded using cause and effect diagram. Setup operation method was selected as the improvement area for this research using weight score matrix. The improvement for bolt forming method was divided into three phases; planning, improvement and implementation.

Planning phase defined necessary information before proceeding with the improvements including forming research team, defining research constraints, research scope, and research timeframe.

In the improvement phase, setup time improvement framework was created. This framework consisted of a two-step improvement which maximized chances to reduce setup time; SMED setup time improvement and refined setup time improvement. The two-step improvement was approached and performed in sequence.

SMED setup time improvement comprised of four conceptual stages. Since machine and tool modification were against company's constraints due to safety issues, SMED improvement involved rearranging setup activities including distinguishing between internal and external setup, and parallel operation.

Refined setup time improvement further analyzed processes and activities of setup operation, and separated improvement into internal setup and external setup. For internal setup improvement, this research was able to identify few setup activities that contributed to most of setup time by Pareto analysis using 20/80 rule. Result from Pareto demonstrated that three setup activities contributed to majority of current setup time. Five whys technique was used to find root causes of each problem. Consequences of root cause identification, process improvements within the company were emerged including revised of Production order, Step adjustment guideline development and training program initiation. Furthermore, spaghetti diagram and 5S system were implemented for both internal and external setup improvement.

Finally, during the implementation phase, all improvements were concluded and prepared for the actual implementation. Two operators were trained to work in parallel and followed improved setup operation procedure. Full implementation was successfully performed. Standard operating procedure was created as a result of successful implementation, to demonstrate standard procedure of bolt forming setup operation in future operation.

The result shown that bolt forming setup time was reduced from 4 hours 9 minutes and 20 seconds to 1 hour 14 minutes and 49 seconds, which was accounted for 70 percent reduction in setup time. The total setup time was also reduced from 4 hours 51 minutes and 35 seconds to 3 hours 3 minutes and 23 seconds with the reduction of 1 hour 48 minutes and 12 seconds or 37 percent. Trial runs and adjustment activity was reduced from 32 cycles with the duration of 49 minutes and 45 seconds to 18 cycles with duration of 32 minutes 27 seconds. The overall equipment effectiveness of bolt forming process was up by 4 percent from 82 percent to 86 percent. Moreover, the interviews of operators reflected good and cooperative results according to the overall setup improvement.

In efforts to achieve setup time improvement, practical problem solving techniques adopted from theory and literature reviews were successfully implemented in this research. Not only this research improved method and procedure of bolt forming setup operation, but also improved operators involving the operation. The reduction of bolt forming setup time offered the company various benefits including the ability to produce at a smaller batch size and avoid overproduction. The company would be able to reduce level of inventory, increase production flexibility, and become more responsive to customers.

7.2 Limitation

The setup time improvement framework was created base on theory and literature reviews with the consideration of bolt forming setup operation and improved implementation in the research's limited time frame. Therefore, there were opportunities to further improve the framework by adding more tools and techniques from theory and literature review to enhance the setup time reduction. And even though the framework was established as a general method to improve setup time, the framework could be further adapted to be more specific to specific type of machine, which was able to obtain the better time reduction results.

7.3 Recommendation

The company must ensure that improvements are being implemented throughout bolt forming process including products, machines and operators, as this research has improved only one product model on one bolt former (BF23) with two operators involved.

Future performance of bolt forming setup operation must be controlled. By creating process improvements such as standard operating procedure and document development in the system are straightforward, the important part that the company should pay attention to is people. The commitment to changes of top down from management to operators is important. Especially, since parallel operation is implemented, coordination between operators must be developed and ensured implementation of improved setup procedure continues. Concept of management of change should be considered.

Another recommendation is on company's management team. As illustrated in five-why analysis, root causes of long setup time led to the negligence of the company. Management team has to realize the important of quick changeover including provide key performance measurement of bolt formers, guidelines for setup operation and operators' skill improvement path. Company must keep in mind that improvement will not work if process is improved but people are not.

There were also limitations during the research including safety and time limitations that prohibited some of improvement actions. Author would like to recommend pursuing opportunity to challenge those limitations. First of all, machine parts modification. Bolt former adjustments and tighten parts are in different sizes which require different size of tools for operation. Improvement technique can be initiated or recommendation can be given to machine maker to apply technique of function standardization to reduce variation of sizes. Moreover, tooling management is one of given recommendation to provide database system to keep track on tooling life and arrangement as part of 5S improvement.

Moreover, this research did not touch upon machine preventive maintenance program since operators provide machine checking frequently and bolt formers are barely broken down. However, it is a necessary topic to prevent loss of production time and also affect bolt former overall equipment effectiveness. Therefore, author would like to recommend a development of standard procedure for preventive maintenance of bolt former.

The next recommendation is to expand setup improvement into other machines in the company, using setup time improvement framework that has been created in this research. Threading process, duration of 45 minutes in current setup operation can potentially be reduced to be a single digit minutes, which increase flexibility, decrease downtime and many more of benefits from setup time reduction.

Lastly, setup operation is a continuous improvement. Therefore, improvement for better results should be continued after the end of this research. This research has used many analyzing tools and techniques to investigate the problems associated with long setup time which can be helpful for the next improvement initiation. For example, primary cause categories in cause and effect diagram can be used to select the next improvement area for bolt forming setup operation. Not only the improvement of bolt forming is recommended, but the improvement of any processes in the company's production line is encouraged. Value stream mapping created by this research can be used to select the next research study. As there are always opportunities for improvement, author would like the company to continue improving the production process capacity and performance.

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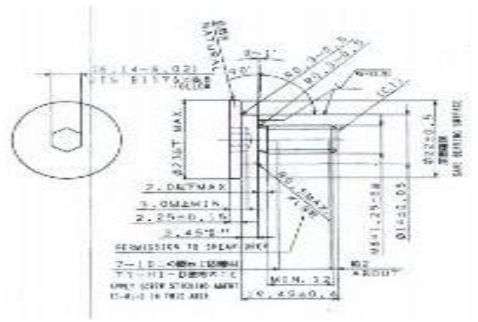
APPENDIX

APPENDIX A: Production order

The first page of Production order shows detail of production including size and dimension of each part of finished product. On the second page, tooling list is illustrated.

Production Order

SEMI FG (Bolt former)



WO160905897

Reference			
Production Number	WO160905897	Drawing No. DWG NO 15-235	
Product Code	*Confidential		
Product Name	Product A		
Customer	*Confidential		
Date	23/04/2016	Finish Date	23/04/2016
Delivery Date	*Confidential		
Production Amount	*Confidential kg	*Confidential	piece

Process No.	Process Code	Process Name	Model	Machine		
1	*Confidential	Bolt forming	*Confidential	BF23		
	Wire Production Code	Name	Amount	Unit	Warehouse	Location
	W0970S435R4	Finished Wire Rod SCM435 09.70 (R4)	100	kg	WH-08B	B

No.	Description	Note
1	Body width (ความโตช่วงรีดเกลียว)	7.05 - 7.09
2	Body length (ความยาวช่วงรีดเกลียว)	15.70 - 15.95
3	Total bolt length (ความยาวช่วงรีดเกลียว+วัดรวมบ่า)	23.50 +/- 0.2
4	Head thickness (ความหนาหัว)	2.10 - 2.40
5	Shoulder width (ความโตบ่า)	13.95 - 14.03
6	Head width (ความโตหัว)	22.50 - 23.00
	FIBER FLOW	FLOW continuous

Note: Product picture is blurred for confidentail details

Remarks	Maker	Checker

Production Order

SEMI FG (Bolt former)

WO160905897

No.	Item number	Tooling name	Location
	TE15-1571-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.1 C006491021	TE store
	TE15-1572-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.2 C006491021	TE store
	TE15-1573-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.3 C006491021	TE store
	TE15-1574-01	HEAD DIE M8x1.25x19.45 P-SK(SP) NO.4 C006491021	TE store
	TE15-1575-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.2 C006491021	TE store
	TE15-1576-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.3 C006491021	TE store
	TE15-1577-01	PUNCH CASE M8x1.25x19.45 P-SK(SP) NO.4 C006491021	TE store
	TE15-1578-01	SECOND PUNCH TIN M8x1.25x19.45 P-SK(SP) 30MM. C006491021	TE store

Remarks	Maker	Checker

APPENDIX B: Detail of setup operation sub-activities

Appendix B1: Current setup operation sub-activities

Machine no.: Bolt former BF23

Product name: Product A

Observation date: 23-Apr-16 (Current Setup Observation 1st time),
07-May-16 (Current Setup Observation 2nd time),
21-May-16 (Current Setup Observation 3rd time)

Step	Activity	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
1	**Prepare finished wire**	**0:06:31**	**0:07:12**	**0:06:44**
	Walk to wire department (60 meters)	0:01:50	0:01:56	0:02:03
	Request for finished wire according to Production order	0:02:49	0:03:34	0:02:51
	Walk back to bolt forming area (60 meters)	0:01:52	0:01:42	0:01:50
2	**Prepare dies and punches**	**0:21:52**	**0:25:45**	**0:23:13**
	Walk to tooling store (20 meters)	0:00:40	0:00:41	0:01:08
	Find the required toolings using incomplete tooling list in Production order as guideline	0:20:32	0:24:29	0:21:33
	Bring all toolings back to bolt forming area (20 meters)	0:00:40	0:00:35	0:00:32
3	**Stop the machine once previous products production is finished**	**0:00:53**	**0:02:09**	**0:02:38**
	Press Stop on machine's control panel	0:00:05	0:00:03	0:00:03
	Lift up the covers	0:00:25	0:00:08	0:00:10
	Life up the gripper stand	0:00:23	0:00:21	0:00:36
	Use cleaning rag to wipe off lubricant oil inside machine	-	0:01:37	0:01:49
4	**Weigh previous products**	**0:08:46**	**0:08:15**	**0:08:08**

Step	Activity	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
	Transfer finished products from product outlet tray into the bin	0:00:10	0:00:14	0:00:11
	Hook finished product bin with the overhead crane	0:02:36	0:01:36	0:02:15
	Transfer finished products bin to the weight scale using overhead crane	0:02:03	0:02:47	0:02:24
	Balance two side of weight scale with dumbbells	0:01:58	0:02:23	0:02:05
	Transfer finished product bin to the WIP area	0:01:59	0:01:15	0:01:13
5	**Fill in Self-Inspection Check Sheet and Production Report for previous products**	**0:09:24**	**0:08:12**	**0:07:54**
	Walk to the BF work station (10 meters)	0:00:15	0:00:18	0:00:13
	Log in the company system and fill in Production Report	0:04:18	0:03:43	0:03:25
	Fill in Self-Inspection Check Sheet using one sample of finished product	0:03:57	0:03:05	0:03:00
	Pull out the Production tag out from previous Production order, walk toward finished product bin and attach Production tag to the bin	0:00:49	0:00:58	0:01:09
	Arrange all forms and put them in the tray at work station to complete previous job	0:00:05	0:00:08	0:00:07
6	**Dismount the previous dies and punches out of machine**	**0:09:49**	**0:10:08**	**0:09:18**
	Find tools for dismounting dies and punches	0:02:00	0:03:22	0:01:33
	Loosen nuts (total of 8 nuts) on die side	0:02:51	0:02:48	0:02:36
	Remove dies step 1 to 4 out of machine and place them on machine	0:01:34	0:01:04	0:01:48
	Loosen double nuts (total of 8 nuts) on punch side	0:02:35	0:02:14	0:02:32

Step	Activity	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
	Remove punches step 1 to 4 out of machine and place them on machine	0:00:49	0:00:40	0:00:49
7	**Dismount the previous wire toolings out of machine**	**0:03:09**	**0:03:12**	**0:04:05**
	Find tools for dismounting wire tooling	0:00:26	0:00:39	0:01:35
	Loosen nuts in wire tooling area	0:02:07	0:01:56	0:01:51
	Remove wire toolings	0:00:36	0:00:37	0:00:39
8	**Dismount the previous grippers out of machine**	**0:01:41**	**0:02:11**	**0:01:56**
	Find tools for dismounting grippers	0:00:09	0:00:25	0:00:25
	Loosen nuts on gripper stand	0:01:05	0:01:05	0:01:05
	Remove 4 sets of grippers	0:00:41	0:00:41	0:00:41
9	**Dismount the previous feeding rollers out of machine**	**0:04:46**	**0:05:06**	**0:04:42**
	Find tools for dismounting feeding rollers	0:00:08	0:00:13	0:00:04
	Loosen nuts on all 4 feeding rollers	0:03:59	0:04:32	0:04:18
	Remove 4 feeding rollers and place them at the feeding roller stand	0:00:39	0:00:21	0:00:20
10	**Clean up the previous dies and punches**	**0:24:31**	**0:23:47**	**0:21:50**
	Find cleaning bucket and fill water in	0:06:28	0:05:14	0:04:10
	Use cleaning rag to clean all toolings and put them in blue bin	0:18:03	0:18:33	0:17:40
11	**Mount new wire toolings onto machine**	**0:06:23**	**0:06:26**	**0:06:23**
	Insert new wire toolings onto their places	0:01:25	0:01:08	0:01:06
	Find tools for tighten the nuts	0:00:07	0:00:14	0:00:15
	Tighten nuts in wire tooling area	0:04:51	0:05:04	0:05:02
12	**Mount new feeding rollers onto machine**	**0:08:27**	**0:09:11**	**0:08:54**

Step	Activity	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
	Take new rollers from feeding roller stand and insert them on their places	0:00:45	0:00:52	0:01:02
	Find tools for tighten the nuts	0:00:20	0:00:18	0:00:14
	Tighten nuts on feeding rollers	0:07:22	0:08:01	0:07:38
13	**Connect finished wire onto machine**	**0:14:56**	**0:14:12**	**0:12:50**
	Use overhead crane to carry new finished wire from finished wire waiting area and place it on wire stand in front of machine	0:02:03	0:01:22	0:01:05
	Remove all the plastic covers and use cutter to cut the tying rod off the finished wire	0:00:59	0:01:58	0:01:31
	Find the loose end of the finished wire rod and pull it onto the straightening rollers	0:04:36	0:04:06	0:03:38
	Operate the straightening rollers using the switch attached to it and adjusting screws connected to straightening rollers for finished wire to smoothly go through all rollers	0:05:43	0:05:07	0:05:01
	Unsharpened the beginning of finished wire using rasp	0:00:42	0:00:37	0:00:30
	Use the switch to feed finished wire through all rollers and into the machine	0:00:48	0:00:52	0:00:57
	Open the front door of the machine to make sure finished wire is also fed through the feeding rollers inside the machine	0:00:05	0:00:10	0:00:08
14	**Mount new grippers onto machine**	**0:05:22**	**0:05:38**	**0:05:21**
	Find tools for tighten the nuts	0:00:08	0:00:09	0:00:09
	Insert new grippers onto gripper stand	0:01:35	0:01:39	0:01:21
	Adjust grippers positions manually and tighten the nuts with tools	0:03:39	0:03:50	0:03:51

Step	Activity	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
15	**Mount new dies and punches onto machine**	**0:25:45**	**0:39:12**	**0:34:15**
	Bring all toolings up onto machine area	0:02:51	0:02:12	0:02:25
	Assemble punch toolings into the case	0:08:19	0:09:40	0:09:03
	Walk to tooling store (20 meters) to get required tooling	-	0:09:25	0:07:46
	Walk back from tooling store (20 meters) to machine	-	0:00:43	0:00:45
	Assemble punch toolings into the case	-	0:03:17	0:01:29
	Insert 4 new sets of punches onto their places	0:03:05	0:02:46	0:02:36
	Find tools for tighten the nuts	0:00:15	0:00:08	0:00:03
	Tighten all nuts on punch side	0:03:37	0:03:55	0:03:51
	Insert 4 new sets of dies onto their places	0:02:39	0:02:14	0:02:02
	Find tools for tighten the nuts	0:00:03	0:00:02	0:00:02
	Tighten all nuts on die side	0:04:56	0:04:50	0:04:49
16	**Trial runs and adjustment of dies, punches and wire toolings**	**0:46:52**	**0:49:45**	**0:47:10**
	Jog machine	*Note 1, Appendix B3		
	Pick up produced product from gripper to check sizes of product using vernier caliper and micrometer			
	Make adjustment *Note 2, Appendix B3			
17	**Test run machine at production speed**	**0:06:14**	**0:06:28**	**0:06:00**
	Press Start machine on control panel	0:00:04	0:00:03	0:00:04
	Walk down to output tray and use vernier caliper and micrometer to measure sizes of produced products	0:06:10	0:06:25	0:05:56

Step	Activity	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
18	**Fill in First Piece Inspection Check Sheet**	**0:12:54**	**0:12:09**	**0:11:51**
	Pick up 3 samples of finished products and walk to the table	0:00:50	0:00:32	0:00:31
	Fill in First Piece Inspection Check Sheet	0:12:04	0:11:37	0:11:20
19	**Inspect the finished products by Quality Control personnel (first time)**	**0:02:34**	**0:01:55**	**0:02:12**
	Walk to QC work station (10 meters) to give sample product to QC personnel with Production order	0:00:31	0:00:34	0:00:38
	QC measure the products according to the Production order and inspect the appearance of no damage or scratch on products	0:02:03	0:01:21	0:01:34
20	**Rework on problematic area of setup operation**	**0:45:33**	**0:33:21**	**0:32:53**
	Determine the incorrect setup for poor quality products and correct it *Note 3, Appendix B3	0:32:05	0:20:16	0:18:52
	Trial runs and adjustment of dies and punches (second time)	0:07:48	0:08:27	0:09:37
	Remove non-conformance products from product outlet tray	0:00:27	0:00:25	0:00:24
	Test run machine at production speed (second time)	0:05:09	0:04:13	0:04:00
21	**Inspect the finished products by Quality Control personnel (second time)**	**0:08:21**	**0:08:03**	**0:07:45**
	Walk to QC work station and ask for inspection	0:00:30	0:00:33	0:00:35
	Walk back to bolt former output tray with QC personnel	0:00:40	0:00:45	0:00:39
	QC measure the products according to the Production order and inspect the appearance of	0:07:11	0:06:45	0:06:31

Step	Activity	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
	no damage or scratch on products			
22	**Return dismantled dies and punches to the storage**	**0:08:20**	**0:09:18**	**0:09:04**
	Use small trolleys to carry the blue bin containing dismantled toolings to tooling store	0:07:27	0:08:07	0:08:00
	Place blue bin onto the "Return tooling" mat inside tooling store	0:00:53	0:01:11	0:01:04

Appendix B2: Improved setup operation sub-activities

Machine no.: Bolt former BF23

Product name: Product A

Observation date: 10-Sep-16 (Improved Setup Observation 1st time),
17-Sep-16 (Improved Setup Observation 2nd time),
24-Sep-16 (Improved Setup Observation 3rd time)

<u>Operator A</u>

Step	Activity (Operator A)	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
1A	**Prepare finished wire**	**0:01:48**	**0:01:20**	**0:01:38**
	Walk to the nearest phone located at QC work station (10 meters)	0:00:32	0:00:25	0:00:34
	Call wire department and request for finished wire according using Production order number	0:00:46	0:00:30	0:00:35
	Walk back to bolt forming area (10 meters)	0:00:30	0:00:25	0:00:29
2A	**Prepare dies and punches**	**0:28:13**	**0:20:24**	**0:18:36**
	Walk to tooling store (20 meters)	0:00:45	0:00:42	0:00:45
	Find the required toolings according to completed tooling list Production order	0:10:52	0:08:50	0:08:45
	Bring all toolings back to bolt forming area (20 meters)	0:00:41	0:00:38	0:00:40
	Assemble toolings into sets for each step of die and punch to go into the machine	0:15:55	0:10:14	0:08:26
3A	**Stop the machine once previous production is finished**	**0:00:51**	**0:00:44**	**0:00:28**
	Press Stop on machine's control panel	0:00:03	0:00:02	0:00:02
	Lift up the covers	0:00:08	0:00:10	0:00:12
	Life up the gripper stand	0:00:11	0:00:12	0:00:14

Step	Activity (Operator A)	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
	Use cleaning rag to wipe off lubricant oil inside machine	0:00:29	0:00:20	-
4A	**Dismount the previous dies and punches out of machine**	**0:06:45**	**0:06:47**	**0:06:28**
	Find tools for dismounting dies and punches on shadow board	0:00:02	0:00:02	0:00:02
	Loosen nuts (total of 8 nuts) on die side	0:02:37	0:02:40	0:02:39
	Remove dies step 1 to 4 out of machine and place them on machine	0:01:19	0:01:05	0:00:56
	Loosen double nuts (total of 8 nuts) on punch side	0:02:03	0:02:15	0:02:00
	Remove punches step 1 to 4 out of machine and place them on machine	0:00:44	0:00:45	0:00:51
5A	**Dismount the previous wire toolings out of machine**	**0:03:03**	**0:03:03**	**0:03:03**
	Find tools for dismounting wire tooling on shadow board	0:00:02	0:00:02	0:00:02
	Loosen nuts in wire tooling area	0:02:18	0:02:15	0:02:12
	Remove wire toolings	0:00:43	0:00:46	0:00:49
6A	**Dismount the previous grippers out of machine**	**0:02:10**	**0:02:09**	**0:02:09**
	Find tools for dismounting grippers on shadow board	0:00:03	0:00:02	0:00:02
	Loosen nuts on gripper stand	0:01:22	0:01:28	0:01:26
	Remove 4 sets of grippers	0:00:45	0:00:39	0:00:41
7A	**Mount new wire toolings onto machine**	**0:06:14**	**0:06:06**	**0:06:21**
	Insert new wire toolings onto their places	0:01:12	0:01:15	0:01:10
	Find tools for tighten the nuts on shadow board	0:00:01	0:00:02	0:00:02

Step	Activity (Operator A)	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
	Tighten nuts in wire tooling area	0:05:01	0:04:49	0:05:09
8A	**Mount new grippers onto machine**	**0:04:41**	**0:04:32**	**0:04:22**
	Find tools for tighten the nuts on shadow board	0:00:02	0:00:02	0:00:02
	Insert new grippers onto gripper stand	0:01:19	0:01:15	0:01:14
	Adjust grippers positions manually and tighten the nuts with tools	0:03:20	0:03:15	0:03:06
9A	**Mount new dies and punches onto machine**	**0:14:56**	**0:13:21**	**0:12:26**
	Bring all toolings up onto machine area	0:02:02	-	-
	Assemble punch toolings into the case	0:01:15	0:01:08	0:01:10
	Insert 4 new sets of punches onto their places	0:02:44	0:03:07	0:02:41
	Find tools for tighten the nuts on shadow board	0:00:02	0:00:02	0:00:02
	Tighten all nuts on punch side	0:03:26	0:03:02	0:03:11
	Insert 4 new sets of dies onto their places	0:02:07	0:02:55	0:02:38
	Find tools for tighten the nuts on shadow board	0:00:02	0:00:02	0:00:02
	Tighten all nuts on die side	0:03:18	0:03:05	0:02:42
10A	***Trial runs and adjustment of dies, punches and wire toolings***	**0:32:27**	**0:26:45**	**0:20:33**
	Jog machine	*Note 1, Appendix B3		
	Pick up produced product from gripper to check sizes of product using vernier caliper and micrometer			
	Make adjustment *Note 2, Appendix B3			
11A	**Test run machine at production speed**	**0:02:00**	**0:01:37**	**0:01:52**
	Press Start machine on control panel	0:00:03	0:00:02	0:00:03

Step	Activity (Operator A)	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
	Walk down to output tray and use vernier caliper and micrometer to measure sizes of produced products	0:01:57	0:01:35	0:01:49
12A	***Inspect the finished products by Quality Control personnel***	**0:01:42**	**0:01:48**	**0:01:37**
	Walk to QC work station (10 meters) to give sample product to QC personnel with Production order	0:00:33	0:00:28	0:00:35
	QC measure the products according to the Production order and inspect the appearance of no damage or scratch on products	0:01:09	0:01:20	0:01:02
13A	***Fill in First Piece Inspection Check Sheet***	**0:11:36**	**0:12:53**	**0:11:53**
	Pick up 3 samples of finished products and walk to the table	0:00:29	0:00:38	0:00:22
	Fill in First Piece Inspection Check Sheet	0:11:07	0:12:15	0:11:31

<u>Operator B</u>

Step	Activity (Operator B)	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
1B	**Weigh previous products**	**0:02:32**	**0:02:17**	**0:01:57**
	Transfer finished products from product outlet tray into the bin	0:00:12	0:00:15	0:00:11
	Hook finished product bin with the digital weight scale which is attached to overhead crane	0:01:28	0:01:12	0:01:03
	Transfer finished product bin to the WIP area	0:00:52	0:00:50	0:00:43
2B	**Fill in Self-Inspection Check Sheet and Production Report for previous products**	**0:07:54**	**0:07:46**	**0:07:40**
	Walk to the BF work station (10 meters)	0:00:29	0:00:26	0:00:31
	Log in the company system and fill in Production Report	0:03:25	0:03:10	0:03:18
	Fill in Self-Inspection Check Sheet using one sample of finished product	0:03:06	0:03:19	0:03:00
	Pull out the Production tag out from previous Production order, walk toward finished product bin and attach Production tag to the bin	0:00:46	0:00:42	0:00:41
	Arrange all forms and put them in the tray at work station to complete previous job	0:00:08	0:00:09	0:00:10
3B	**Dismount the previous feeding rollers out of machine**	**0:04:53**	**0:04:50**	**0:04:49**
	Find tools for dismounting feeding rollers on shadow board	0:00:06	0:00:03	0:00:02
	Loosen nuts on all 4 feeding rollers	0:04:28	0:04:29	0:04:25
	Remove 4 feeding rollers and place them at the feeding roller stand	0:00:19	0:00:18	0:00:22

Step	Activity (Operator B)	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
4B	**Mount new feeding rollers onto machine**	**0:09:47**	**0:08:27**	**0:08:26**
	Take new rollers from feeding roller stand and insert them on their places	0:00:49	0:00:44	0:00:39
	Find tools for tighten the nuts on shadow board	0:00:06	0:00:03	0:00:02
	Tighten nuts on feeding rollers	0:07:43	0:07:40	0:07:45
	Operator takes a break	0:01:09	-	-
5B	**Connect finished wire onto machine**	**0:12:30**	**0:12:45**	**0:12:12**
	Use overhead crane to carry new finished wire from finished wire waiting area and place it on wire stand in front of machine	0:01:00	0:01:12	0:01:30
	Remove all the plastic covers and use cutter to cut the tying rod off the finished wire	0:02:14	0:01:28	0:01:58
	Find the loose end of the finished wire rod and pull it onto the straightening rollers	0:03:34	0:03:47	0:03:03
	Operate the straightening rollers using the switch attached to it and adjusting screws connected to straightening rollers for finished wire to smoothly go through all rollers	0:04:33	0:05:08	0:04:24
	Unsharpen the beginning of finished wire using rasp	0:00:20	0:00:25	0:00:31
	Use the switch to feed finished wire through all rollers and into the machine	0:00:44	0:00:39	0:00:40
	Open the front door of the machine to make sure finished wire is also fed through the feeding rollers inside the machine	0:00:05	0:00:06	0:00:06
6B	**Clean up the previous dies and punches**	**0:21:09**	**0:22:23**	**0:21:41**
	Find cleaning bucket and fill water in	0:04:28	0:05:18	0:04:30

Step	Activity (Operator B)	Duration (h:mm:ss)		
		1st time	2nd time	3rd time
	Use cleaning rag to clean all toolings and put them in blue bin	0:16:41	0:17:05	0:17:11
7B	**Return dismantled dies and punches to the storage**	**0:08:12**	**0:08:32**	**0:08:56**
	Use small trolleys to carry the blue bin containing dismantled toolings to tooling store	0:07:13	0:07:34	0:08:00
	Place blue bin onto the "Return tooling" mat inside tooling store	0:00:59	0:00:58	0:00:56

Appendix B3: Notes for setup operation sub-activities

Note 1

Time for trial runs and adjustment sub activities cannot be easily separated. There are 3 main sub activities that are done repeatedly i.e. jog machine, pick up product from gripper to measure using vernier caliper and micrometer, and make further adjustment. The repeated operations are done until products are fit to specification written in Production order.

Note 2

Adjustment activity includes loosen adjustment lock, make adjustment and tighten adjustment lock.

Note 3

Incorrect setup that led to poor quality product can cause by different reasons. In three recorded setup operations, reworks were caused by reasons described below.

Rework on setup operation 1^{st} time:	Small scratch mark was found on the product due to sharpness of grippers.
Rework on setup operation 2^{nd} time:	Product head was unbalanced in left and right aspect
Rework on setup operation 3^{rd} time:	Product size (body length and total bolt length) were too close to maximum allowable values.

APPENDIX C: Training List

Training will be held on the first day of employment after company induction procedure. New operators will be trained total of 5 courses with total duration of 2 hours and 30 minutes. Trainers are required to mentioned mandatory details of each training course as written in table below.

Course No.	Training Title	Duration (min)	Trainer
1	**Introduction to Bolt former**	30	Lead operator
	- Bolt former configuration and component		
	- Machine operation and maintenance		
2	**Setup Operation Inputs**	30	Lead operator
	- Production order		
	- Step adjustment guideline		
	- Finished wire		
	- Toolings		
3	**Process Control**	30	Lead operator
	- Standard operating procedure		
4	**Output Procedure**	30	Lead operator
	- Finish production forms		
	- Output waiting area		
5	**Quality Check**	30	Quality Control Personnel
	- Finished product quality check		
	- Common mistakes		
	- Quality control lunch and learn training		

VITA

Miss Napin Viriyasathien was born on 21st December, 19990 in Bangkok, Thailand. After completing her high school from Mater Dei School in 2009, she pursued her bachelor degree in Chemical Engineering at Sirindhorn International Institute of Technology (SIIT), Thammasat University. She completed her bachelor degree in 2013 and was employed by WorleyParsons (Thailand) Limited as a Process Engineer. After one year of her working career, she undertook her dual Master degree program in Engineering Management offered by Chula Systems Engineering (CUSE), Chulalongkorn University and Engineering Business Management offered by Warwick Manufacturing Group (WMG), University of Warwick.