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Setup Time Reduction in a Reciprocating Compressor Manufacturing Company: Lean Culture for Sustainable Development and Competitiveness

Kittiwat Sirikasemsuk[1]*, Pichawadee Kittipanya-ngam[2], Pradthana Rattanapuchong[3], Kanogkan Leerojanaprapa[4]

Abstract

Each month, the compressor production case study business produced fewer housing components than anticipated. The data gathered showed that the production changeover time for AE compressor housing was 4,733 seconds (or around 1.3147 hours per model change), which seemed to be a longer timeframe. This study's objective was to use the single minute exchange of dies (SMED) methodology from the lean concept to shorten the time needed for the housing manufacturing of AE compressor types. This study suggested the following key solutions as useful guidelines: moving as much work from internal to external as possible; creating a suitable screw fastening clamp (i.e., an M24 t-slot bolt) to facilitate and simplify work; and designing die stoppers to help with locating the die. A 61.86% shorter changeover time now exists.

Keyword: *Setup Time Reduction, Single Minute Exchange of Dies, Poka-yoke Method, Lean Way, Sustainable Development, Reciprocating Compressor.*

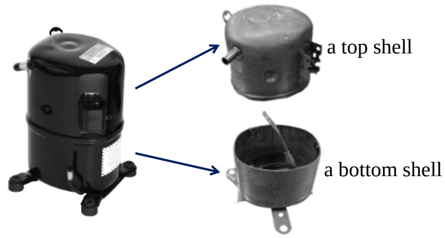
Introduction

Due to the wide range of consumer needs and the intense competition, an organization needs ongoing development. Popular techniques for cutting costs and boosting manufacturing process flexibility involve lean manufacturing. This enables companies to respond to customer requests more swiftly. Lean and sustainable organizational practices encourage more efficient operations and fiercer competition. Manufacturing changeover time is a waste because it doesn't improve the product in any way. In order to satisfy the diverse needs of clients, it is a support activity that must be added. Production workers are frequently forced to stop working during setup. Reduced changeover times will result in longer production times.

This research was based on a case study company that makes and sells hermetic reciprocating compressors for air conditioners and refrigerators. These compressors are sold both domestically and internationally. The external components of reciprocating compressors consist of a top shell and a bottom shell, as shown in Figure 1.

[1]Department of Industrial Engineering, School of Engineering, King Mongkut's Institute of Technology Ladkrabang Bangkok 10520, Thailand
[2]Department of Operations Management, Thammasat Business School, Thammasat University, Pranakorn, Bangkok 10200, Thailand
[3]Department of Industrial Engineering, School of Engineering, King Mongkut's Institute of Technology Ladkrabang Bangkok 10520, Thailand
[4]Statistics Department, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand
*Corresponding Author email: kittiwat.sirikasemsuk@gmail.com

Figure 1: Main external components of a sealed reciprocating compressor



The average monthly changeover time of the bottom shell compressor AE series was 8.19 percent of the available work time in 2019. Consequently, this study was conducted to improve the changeover of the bottom shell compressor AE series by employing lean manufacturing focusing on the implementation of SMED techniques, and the poka-yoke technique. Finally, practical recommendations were provided.

Literature Review

Theories of Lean Manufacturing, poka-yoke, and SMED

Lean manufacturing is a production system that focuses on eliminating or reducing waste within every work process or emphasizing increasing value-added activity, resulting in a smoother flow of objects to meet the customers' needs for quality, delivery time, quantity, product diversity, and cost. It also emphasizes minimizing the use of resources (Taboada, 2021). Lean manufacturing uses fewer raw materials, including inventory during processes, investments, workers, time, space, tools, and equipment, boosting production efficiency (Taboada, 2021; Patel et al., 2014). The five principles of lean manufacturing are as follows: (Patel et al., 2014; Earley, 2016)

1. Value.
2. Value stream mapping.
3. Flow improvement.
4. Pull system.
5. Perfection persuasion.

Poka-yoke, mistake-proofing in Japanese, is a technique for preventing human errors in production or assembly and making quick fixes. It is a highly effective technique to focus on zero-defect manufacturing (Shingo & Dillon, 1989). Physical waste from production employees can be resolved by designing new production processes and new goods. There are the following two principles of poka-yoke:

Principle 1: A 100% inspection of all workpieces during production. It automatically directs the movement of every workpiece to prevent waste.

Principle 2: The system sends workpieces "warning" or "stop" signals if there is a problem.

Single-Minute Exchange of Die (SMED), also known as Quick Changeover, is a technique used to reduce the setup time to under 10 minutes (or in single-digit minutes). Production changeover period begins with the final high-quality part and ends with the first new high-quality part (Shingo, 1996; Shingo & Dillon, 2019). To achieve lean manufacturing, SMED technique is used as a component of TPM and the continuous improvement process (Sun et al., 2003). Shiego Shingo developed the SMED technique in 1969 while employed as an engineer at Toyota Motor Corporation. He was tasked to reduce machine setting time from 1-2 hours to a few minutes (Shingo & Dillon, 1989).

Die replacement consists of the following five steps: 1. tools and equipment preparation; 2. die dismantling; 3. die installation; 4. machine adjustment; 5. trial run. The five-step technique for quick machine setup are the following: (Agustiady & Cudney, 2022)

1. study in depth the process for adjusting the current machine.
2. separate internal and external setup.
3. remove external setup from the production changeover period to operate "in advance" or "after running".
4. convert the internal work to external work.
5. simplify the internal and external machine installation tasks.

It is noted that the internal setup, which stops the machine, adjusts the machines, tools, or other equipment on the production line. The external setup installs the machines, tools, or equipment related to a production model change without stopping the machine. Hence, time spent in external setup is not included in the production changeover time (Shingo, 1996; Shingo & Dillon, 2019). Furthermore, there are other improvement changeover techniques, e.g., the one-touch exchange of dies (OTED), the no-touch exchange of dies (NTED), and the zero setup. The OTED principle allows technical staff to switch devices in less than 100 seconds with a single button press. The NTED involves no humans at all. The zero setup is equivalent to one-minute setups (Protzman et al., 2018).

It is noted that poka-yoke and SMED are tools of lean manufacturing (Rahardjo et al., 2023). Lean manufacturing, poka-yoke, and SMED have been applied in the following industries: the automotive industry, consumer electronics, building materials and supplies, and the chemical industry. Readers are referred to the papers of Rewers et al. (2016) and Maware et al. (2022) for a comprehensive review of the more specific examples of how lean manufacturing, poka-yoke, and SMED have been applied.

Related Research

Several studies, including Carrizo Moreira & Campos Silva Pais (2011), Morales Méndez & Silva Rodrguez (2016), Dhankhar & Kumar (2016), Filla (2016), and Ahmad & Soberi (2018), relied on Shiego Shingo's SMED principle to reduce changeover time by pushing or converting internal setup to external setup. Further significant details are provided below.

Carrizo Moreira & Campos Silva Pais (2011) studied a die-making firm by preparing a new set of dies near the machine before machine setup. The top management was told to create a new organizational structure with SMED teams, production process control, and new technology development. Morales Méndez & Silva Rodriguez (2016) used the principles of SMED and overall equipment effectiveness (OEE) to reduce the setup time of the interconnection axle. The improvements raised the OEE value from 77 to 85%. Dhankhar & Kumar (2016) reduced the shock-absorber assembly line time and improved its balance. In addition, the concept of the SMED technique was introduced by converting the internal setup to an external one.

Filla (2016) used data from Filla (2014) to study the reduction of machine setup time at a flat glass processing company with a high-mix production line and discovered that machine setup (changeover) was the major cause of all downtime. The changeover workers were reassigned to set up the machine. Ahmad & Soberi (2018) implemented SMED techniques with a new framework, including elimination, conversion of internal to external work, combination and parallelization, and simplification. The improved 5-axis trimming changeover process was carried out in business that produces advanced composites. There were three main solutions that were implemented: tagging system design, scanning system application, and router jig handling procedure revision.

Several other studies did not analyze and convert internal to external work to decrease production changeover time. For example, Lozano et al. (2017) analyzed the factors of success in using SMED in the food sector and stressed the need for machine setup manuals to provide a standard of setup. In addition, they offered machine setup performance indicators, including MTBF, MTTR, and OEE. Hence, Cakmakci (2009) emphasized the importance of paying attention during quick exchanges. In a case study on an automobile industry method for making rims, a process capability analysis was used to measure quick changeover improvement.

Sabadka et al. (2017) focused on developing a new system based on Cakmakci's research (2009). They reduced shaft manufacturing changeover time by developing a universal palette for shafts. In the works of Cakmakci & Karasu (2007) and Cakmakci (2009), they designed and installed new stopper studs on the lower boring machine to easily center the die for air hole boring. Cakmakci & Karasu (2007) also designed a forklift equipped with mechanical pushers and pullers to transfer the die to the stopper studs.

Boran & Ekinciolu (2017) proposed in an aluminum profile factory an ergonomic risk assessment technique coupled with the SMED method to continuously reduce setup time. The Sue Rodgers method, also called the muscle fatigue assessment (MFA) method, was used. Patel et al. (2001) discussed the problem at a small aerospace component manufacturer. The company president erroneously assumed that machine setups were profitable. As a result, they were unaware of the need for setup time solutions. The use of SMED and the Poke Yoke reduced the machine setup time to 15 minutes. Fouling pins and offset holes are straightforward poka-yoke devices that have helped maintain repeatability and quality. This research also examined the company's managers' problems in cutting down on setup time and avoiding mistakes.

The literature review revealed that SMED reduced machine setup time in numerous industries by converting internal to external activity. The production changeover procedure was reproduced. Singh & Khanduja (2011), Bevilacqua, et al. (2015), and Ahmad & Soberi (2018) found that lean tools with various methodologies aided production changeover procedures. However, there was limited research on the reduction of setup times (quick changeover) among reciprocating compressor manufacturers. This study included the use of lean tools (such as SMED, poka-yoke, design for assembly, re-layout, etc.) to solve the problem of long-run changeover time at a Thai compressor manufacturer. This research shows how to cut down production changeover times by solving sustainability problems with a modest investment.

Research Methodology

The researcher conducted a study based on the principles of systematic problem-solving research, utilizing SMED processes by dividing activities into subtasks and implementing the stages outlined below:

1. investigate basic information and define key performance indicators
2. study and record work process
3. analyze the causes of the problem affecting the changeover time.
4. find solutions and compare performance.

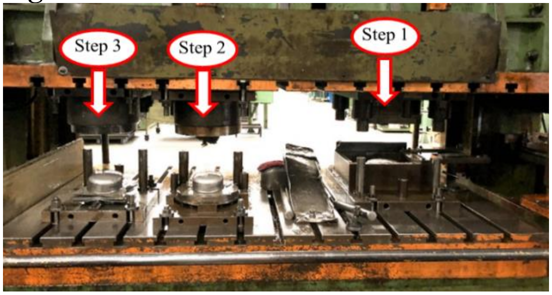
Investigate Basic Information and Define Key Performance Indicators

The researcher chose to study the bottom-shell compressor AE series, which is used in refrigerators, due to its high production volume. The bottom shell compressor took longer to changeover than the top shell compressor. In 2019, the changeover time averaged 1,076 minutes, or 8.19% of the monthly working period, representing the highest waste of time. Second, the machinery malfunction time was at 1.61% and the production plan at 0.98%. It was noted that average monthly working time was 87.48% productivity. The changeover time during the process of adjusting the drawing machine on the bottom shell compressor AE series was measured in this study (per time). The current average time was 4,733 seconds (or 1.3147 hours per time).

Study and Record Work Process

The company in the case study made reciprocating compressors in seven steps: 1. compressor body housing (which is the focus of this study); 2. subassembly machining; 3. drivetrain manufacture; 4. assembly-suction unit; 5. compressor assembly; 6. final compressor testing; and 7. storage. The lower housing process used sheet metal drawing principles. Figure 2 illustrates the company's semi-automatic presses. Three work processes employed distinct sub-dies in this system:

Figure 2: The front side of the machine used to manufacture the bottom shell of the AE series compressors.



Step 1: The blanking and drawing process began with the steel sheet coils being fed into another steel feeding machine to deliver them to the drawing machine in Step 1. The drawing machine cuts the metal sheet along the workpiece's specified border. This metal sheet was formed to house the metal sheet using punches and dies to shape the workpiece.

Step 2: The flanging process involved pressing the finished workpiece from Step 1 against the curve.

Step 3: The trimming process involved taking the workpiece from Step 2 and cutting off the excess edge of the workpiece to obtain the required size and shape of the bottom shell.

The manufacturing of compressors for the AE series included a total of 22 models, which might be categorized into three categories based on the following major die sets: KEH440 die sets, KEH441 die sets, and KEH443 die sets. Each die set consisted of three subsets of dies separated by three steps, making a total of nine die subsets. Two mechanics (mechanics 1 and 2) were required per time to set up the deep drawing machine for the compressor bottom shell. The bottom shell-compressor setup activities could be separated into the following seven categories.

Group A was a production plan review process.
Group B was in charge of removing the previous dies from the drawing machine.
Group C was the process of storing the previous set of dies and replacing them with the new set.
Group D was the process of assembling the steel coils and adjusting the steel feeding machine applied to the drawing machine.
Group E was the process of adjusting the die's height.
Group F involved the installation of a new set of dies in the drawing machine.
Group G was a process of drawing and inspecting the workpiece.

The first mechanic in the compressor body forming department office assessed the daily production schedule. He wheeled a cart of tools and equipment from the equipment storage room to the drawing machine. The first and second mechanics dismantled the previous dies.

The first mechanic assembled the steel coil and installed the drawing machine's steel feeder after die removal. The second mechanic assisted the forklift operator lift and store the previous die, and load and install a new die. While the second mechanic and forklift operator worked, the first mechanic adjusted the die height before assembling it at the drawing machine. After that, a forklift operator transported the adjusted die to the drawing machine. Then, the first and second mechanics assembled new dies on the drawing room. The first mechanic stamped and inspected the workpiece after assembling the new dies. The new die's setup must be adjusted until the workpiece's measured value matches the standard. Figure 3 shows a multiple activity chart that could explain the relationship order of the seven groups of activities.

Analyze Root Causes of Problems and Design a Solution

The changeover procedure for the compressor bottom shell was studied using a flow chart and a work-flow diagram based on the two workers (mechanic 1 and mechanic 2). Figure 3 shows a multi-activity chart that could explain their relationship. Figure 3 reveals that the overall time duration was 4,733 seconds per setup time across all of the employees. Mechanic 1 worked 4,680 seconds and idled 53 seconds. Mechanic 2 worked 2,929 seconds and idled 1,804 seconds.

Root Cause Analysis - Group A

In Group A, the most time-consuming activity was reconfiguring the production plan, which took 1,804 seconds. The first mechanic had to walk from the machine area to the office each day before changing the model to acknowledge the production plan and arrange it. Mechanic 1 had to categorize and prioritize manufacturing groups in order to reduce model changeovers and setups. Concurrently, the second mechanic was waiting for the first mechanic's changeover plan. The main idea for improving the situation was to convert internal to external activities.

Figure 3: A multi-activity chart of the model changeover of the compressor bottom shell

No	Mechanic 1	Time (seconds)	Mechanic 2	Time (seconds)	Drawing machine	Time (seconds)
1.	A: a production plan review process	1,804	Idle	1,804	Idle	1,804
2.	B: removing the previous dies from the drawing machine	307	B: removing the previous dies from the drawing machine	307	Idle	307
3.	D: a process of assembling the steel coils and adjusting the steel feeding machine applied to the drawing	436	C: a process of storing the previous set of dies and replacing them with the new set	885	Idle	885
4.	E: a process of adjusting the die's height	396				
	Idle	53				
5.	F: an installation of a new set of dies in the drawing machine	1,548	F: an installation of a new set of dies in the drawing machine	1,548	Idle	1,548
6.	G: a process of drawing and inspecting the workpiece	189	G: a process of drawing and inspecting the workpiece	189	Machine working	189
	Total working time	4,680	Total working time	2,929	Total working time	189
	Total idle time	53	Total idle time	1,804	Total idle time	4,574
	Total	4,733	Total	4,733	Total	4,733

Operators working on a machine (hatched) | Independent working (black) | Idle (white)

Root Cause Analysis - Group B

Group B's activities were removing the die from the drawing machine. Prior to the improvement, the task required 307 seconds per time. It was found that there were two different sets of screw fastening systems. Set 1 consisted of M20 and M24 socket cap screws, flat washers, and t-slot nuts. The M20 and M24 hexagon key wrenches had to be used to unscrew the M20 and M24 screws.

Set 2 consisted of M20 and M24 t-slot bolts, flat washers, and hexagon nuts. The M20 and M24 hex nut wrenches were used to unscrew the M20 and M24 hexagon nuts. Details are provided in Table 1.

Each die set (KEH440, KEH441, and KEH443) used a unique set of fastening clamps. Finding and selecting screw-fastening clamps and their tools was required for congruently fastening the die. Furthermore, the M20 and M24 wrench tightening tools can be switched.

As a result, the researchers proposed developing a universal die fastening clamp for all dies. The mechanics used only one kind of wrench. Furthermore, die fastening clamp storage has been redesigned for ease of use.

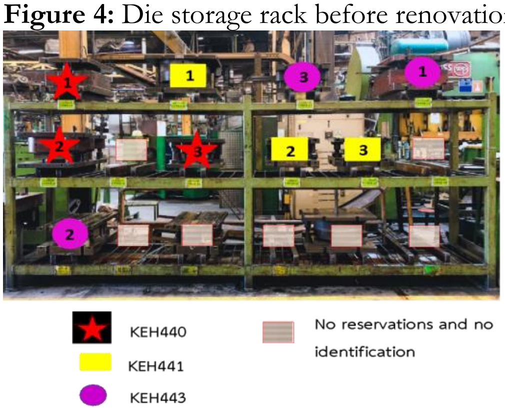
Table 1: Variety of screw fastening clamps (before improvement)

Set 1		Set 2	
	M20 and M24 socket cap screws, with lengths of 80, 90, and 100 mm.		M20 and M24 hexagon nuts
	flat washers		flat washers
	M20 and M24 t-slot nuts		M20 and M24 t-slot bolts, with a length of 80 mm.

Root Cause Analysis - Group C

Group C's activities were storing the previous die and moving out the replacement die. Working time averaged 885 seconds before the improvement. To store and search for new sets of dies, it needed an empty space. The location was not specified. Figure 4 depicts the scattering of three subsets of the same major die set.

Figure 4: Die storage rack before renovation



Furthermore, the drawing machine and storage were isolated by long distances. Thus, repositioning the die was pointless. This study suggested building a storage facility beside the drawing machine. In the new area, nine die subsets for KEH440, KEH441, and KEH443 were separated by signs indicating their non-swappable positions.

Root Cause Analysis - Group D

Group D's activities included assembling steel coils and installing the steel feeding machine into the drawing machine. This group took 436 seconds to complete by crane. The investigation uncovered large and heavy steel coils. Furthermore, the steel feeder was difficult to set up. As a result, internal and external work became another concept. A steel coil mechanism was planned. However, there was a cost constraint due to the large steel coils. As a result, this concept is currently outside the scope of this study, but it may be provided as a future recommendation for the organization.

Root Cause Analysis - Group E

The analysis of Group E's activities shows that altering the die's height took 449 seconds before improvement. The first mechanic had to set the step 1 die's height to match the AE sub-model. It was noted that the dies in steps 2 and 3 did not require height setting. The researcher proposed assigning mechanics 1 or 2 to set up 30 minutes before the changeover to externalize the work.

Root Cause Analysis - Group F

The analysis of Group F's activity shows that assembling new dies onto a drawing machine took 1.548 seconds before its improvement. Putting a new die on a drawing machine took the second most time, after group A checked the production plan.

The mechanics needed to work together to assemble the die. It was critical to locate various types of equipment and screw-fastening clamps.

Group B disassembled old dies, while Group F assembled new dies.

In this section, two activities were discussed:

1. Forklift operators moved dies to drawing machines. They had to focus on the location and go back and forth several times through trial and error in order to get the dies as close to the cushion hole as possible.
2. The die was aligned with the cushion hole after being placed on the machine. In each of the three processes, Mechanics 1 and 2 had to align the sub-dies with the cushion hole.

Under the poka-yoke concept, two strategies were employed to increase work efficiency and convenience:

Strategy 1: Design a stopper to assist in setting the location of the dies.

Strategy 2: Create a steel forklift wheel stop.

Using the flow process chart and brainstorming ideas by the relevant teams, Figure 5 shows a tree diagram that might analyze and determine the problem's cause.

Results

The researchers studied six SMED and poka-yoke problem management techniques based on the root cause analysis of the aforesaid issues:

Strategy 1: Externalize internal work

Strategy 2: Create a new screw fastening clamp.

Strategy 3: Design a stopper to assist in setting the location of the die.

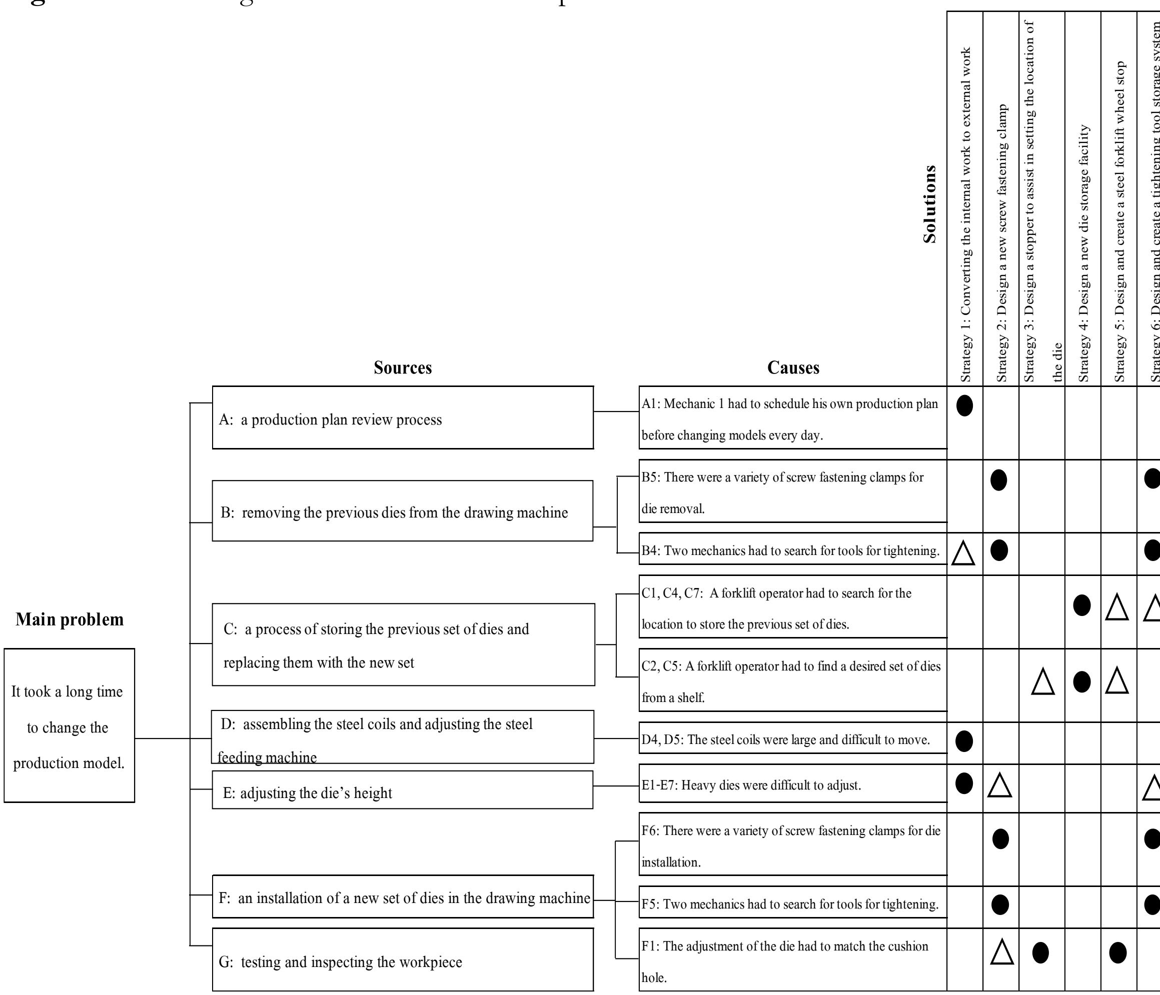
Strategy 4: Design a new die storage facility

Strategy 5: Design and create a steel forklift wheel stop.

Strategy 6: Design and create a tightening tool storage system.

Figure 5 shows that one technique can address many causes. For example, Strategy 1, "Convert the internal to external work," helped groups A, B, D, and E.

Figure 5: A Tree diagram showed the relationship between causes and solutions.



Strategy 1: Converting the internal work to external work

Before the improvement, machine downtime changeover procedure activities were internal. The first mechanic had 34 internal works, the second had 24. This group of works delayed the changeover.

To reduce machine downtime, several internal jobs were converted to external tasks following an analysis. Table 2 shows that mechanic 1 activities in groups A, B, D, and E were converted to external works. Moreover, mechanic 2's work was not convertible.

Table 2: Converting the internal activities to external activities

Group	Activities	Time (Seconds)	Internal works	External works
A	A1: Walk to the tank drawing department's office.	15		√
	A2: Check the daily production schedule.	697		√
	A3: Arrange the production plan.	1,092		√
B	B1: Walk to the equipment storage room.	26		√
	B2: Wheel a cart containing tools and equipment to the bottom shell drawing machine.	30		√
	B3: Press the "Power" and "Start" buttons to activate the drawing machine. Press the button to move Ram down to the die-height point.	15	√	
	B4: Pick up a wrench from a cart containing tools and equipment.	5	√	
	B5: Disassemble the screws that connect the top of the die to the ram and the bottom of the die to the bolster in all three steps.	176	√	
	B6: Place the wrench on a cart containing tools and equipment.	5	√	
	B7: Press the button to move the ram up to the top dead center.	15	√	
	B8: Move all 3-step dies to the back of the drawing machine from the front position.	35	√	
D	D1: Walk to the steel coil storage area.	15	√	
	D2: Assemble the steel coils on the crane.	83		√
	D3: Use a crane to lift the steel coils to the steel feeder.	60		√
	D4: Assemble the steel coil onto the steel feeder.	210	√	
	D5: Set up the steel feeder with the drawing machine.	68	√	
E	E1: Walk to the tool storage area.	20		√
	E2: Pick up the metal plate on the tool storage rack.	16		√
	E3: Walk to a table to adjust the die's height.	10		√
	E4: Pick up the air impact wrench to disassemble the die in Step 1 (new set).	225		√
	E5: Bring the steel plates to the die for assembly.	37		√
	E6: Tighten the steel plates with the air impact wrench in Step 1 (for the new set), then assemble as before.	58		√
	E7: Walk to the bottom shell drawing machine.	30		√
	E8: Wait for the forklift driver to bring the die for Step 1 (the new set) to the drawing machine and place it on the bolster.	53	√	

Table 2 shows that when converting internal setup works to external setup works, the first mechanic had 20 internal and 14 exterior setup works. Internal work might take 2,234 seconds instead of 4,733.

Furthermore, all of Group A's production plan evaluation activities were converted to external work and delegated to the foreman. Hence, mechanics 1 and 2 may immediately join group B's activity.

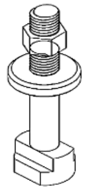
Strategy 2: Design a new screw fastening clamp.

Prior to the improvement, each fastening clamps had various types of systems. M20 and M24 screws, as well as socket cap screws and t-slot bolts, were used (see Table 1). The mechanics had to switch between tools and find suitable die fastening clamps, which took longer. The identical die fastening clamp, as shown in Figure 6, was designed to fit all dies, making it more efficient and convenient. The new die-fastening clamp was composed of three simple parts:

- M24 wide-base t-slot bolts, which were developed from the original t-slot bolt. This specially designed bolt was easier to tighten and remove and had greater holding strength.
- M24 flat washers
- M24 hexagon nuts

It was noted that the M20 cushion holes in some dies were expanded to M24 size.

Figure 6: Screw fastening clamps (after the improvement).



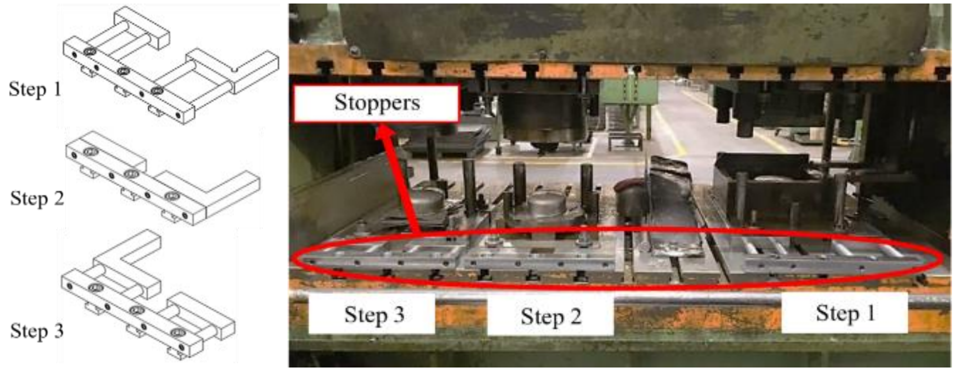
a) the designed M24 t-slot bolt

b) the real M24 t-slot bolt

Strategy 3: Design a stopper to assist in setting the location of the die

From the analysis of Group F activity, it was found that two mechanics had to repeatedly knock on and shift on the die to match the position of the cushion hole. Then, the screws were fastened to the die. Hence, assembling new dies was time-consuming. In this research, stopper devices were designed using the poka-yoke technique to install on the lower machine table. Figure 7 shows how the stopper device helped set the die's location, so it did not go too far forward.

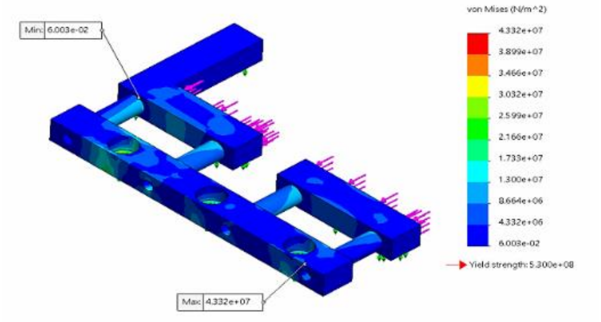
Figure 7: Stopper device designed to assist in setting the location of the die (after the improvement)



Note: Front view of the machine

All three stopper devices were made of S45C (JIS Standard) steel, which was stronger than general structural steel and was commonly used in the manufacture of jigs and fixtures. Figure 8 shows the finite element method analyzing the structure's strength. The stopper devices with a safety factor greater than 12 were less likely to break.

Figure 8: Example of finite element simulation results



Strategy 4: Design a new die storage facility.

The previous set of dies was removed from the drawing machine and stored on a shelf. Finding new dies took a long time after that. The three dies in the same set on the shelf were clearly spaced apart. Die names were not used to identify the dies and dies from other departments were mixed in the storage location. Because the drawing machine and storage were so far apart, Group C's activities wasted time.

The researcher conducted a survey and identified new areas near the drawing machine. The related die sets (a total of 9 subsets) were relocated to the new area (as depicted in Figure 9) without being mixed with dies from other departments. To match the three primary die sets, a new die shelf with three levels and a label for storage was created.

With improved results, the distance required to move the die could be reduced from 120 meters to 30 meters.

Strategy 5: Design and create a steel forklift wheel stop

After lifting a new set of dies to the drawing machine, the forklift driver had to drive the forklift back and forth to place the die as close to the cushion position as possible. Figure 10 shows a steel forklift wheel stop 80 cm from the machine.

The forklift wheel stop prevented the forklift from placing the die too shallowly, while the lower machine table stopper prevented the die from sliding forward. As a result, the first and second mechanics had to move the die in all three steps to match the cushion hole faster.

Also, this kind of system was needed and put in place so that the dies could be stored on shelves.

Strategy 6: Design and create a tightening tool storage system

Both the M20 and M24 wrenches were previously placed on the equipment-containing cart. A novel idea was to keep tightening tools next to the machine rather than on the cart. Figure 11 shows the remaining M24 wrenches from a single-design die fastening clamp. There were two mechanics, which meant two M24 wrenches.

Figure 9: Designing a new storage.

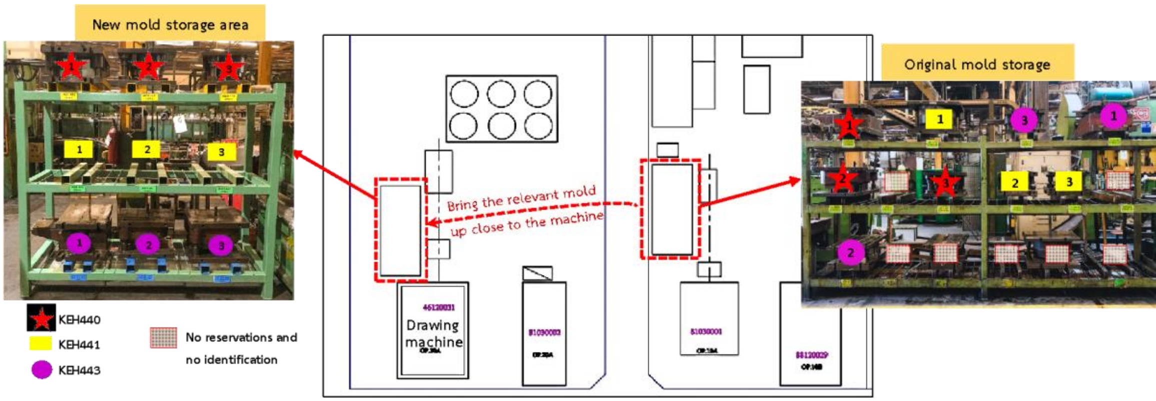


Figure 10: Design of a steel forklift wheel stop for placing the die.

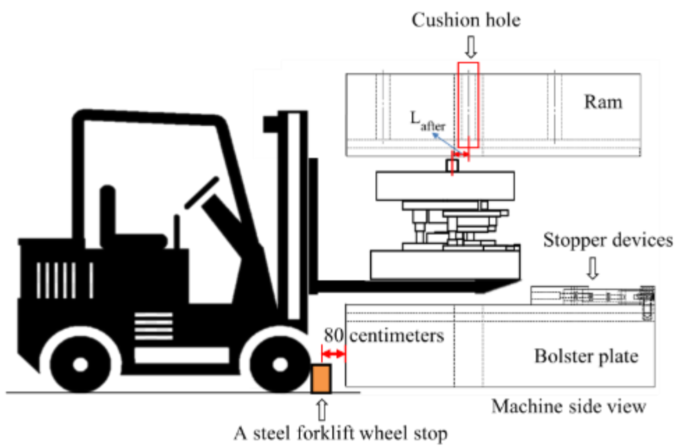


Figure 11: The tightening tool storage area after the improvement.

Performance and Comparison

From Figure 5, each strategy can address various problems. For example, Strategy 1—converting internal to external work—solved actions in Groups A, B, D, and E. Strategies 2 (creating a new die fastening clamp) and 6 (developing a tightening tool storage system) aimed to reduce Group B and F's activity time. The results are shown in Table 3.

Table 3: Comparison of results based on research indicators

Indicators	Value before improvement	Value after improvement
KPI 1: The production changeover time	4,733* seconds	1,805** seconds
KPI 2: Time spent working for each mechanic.		
The first mechanic (mechanic 1)	4,680 seconds	1,766 seconds
The second mechanic (mechanic 2)	2,929 seconds	1,598 seconds

Note * 4,733 seconds = 1.3147 hours,

** 1,805 seconds = 0.514 hours

The following details about reducing time in the main group activities were provided:

Group A, which was reviewing the production plan, was turned into external work. This saved 1,804 seconds of internal work time.

Group B, the time it takes to take the old dies off the drawing machine has gone from 307 seconds to 160 seconds.

Group C, which stores and replaces dies, took 885 seconds to 305 seconds.

Group F, which installs new set of dies into the drawing machine, has been reduced from 1,548 to 1,124 seconds.

Summary and Guidelines for Changeover Process

The bottom shell change was time-consuming, which was the biggest issue in this study. As a result, product numbers fell short. The SMED and poka-yoke techniques were used to solve the problem. This research began with the analysis of the bottom shell compressor changeover process. Internal setup activities were analyzed and converted as much as possible into external setup activities. The poka-yoke technique, based on the lean concept, simplified each activity. The time spent on the changeover process can be reduced by 61.86%, from 1.3147 hours to 0.514 hours per time, increasing production to 154 pieces per time. This study also suggests the following six measures or strategies for reducing the time required for production changeover setup:

Strategy 1: Change internal work to external work as much as possible according to the principles of SMED.

Strategy 2: Create a new screw-fastening clamp that can be used anywhere.

Strategy 3: Create a stopper on the lower machine table to help in positioning the die and prevent the die from sticking out too far into the machine.

Strategy 4: Design a new die storage facility close to the relevant machines and separate relevant dies for the new storage facility.

Strategy 5: Design and create a steel forklift wheel stop in order to prevent placing the die before it reaches the mounting holes.

Strategy 6: Design and create a tightening tool storage system by hanging related tools on the side of the machine.

The SMED approach's fundamental method was described as Strategy 1, while Strategies 3 and 5 were based on the principle of the poka-yoke technique. In addition, Strategies 2, 4, and 5 were joint solutions under SMED and poka-yoke techniques, including the 5S principle. It was emphasized that Strategy 3 was an innovation as a result of this study.

By reducing waste and costs, the lean manufacturing implementation process can strengthen strategic resources, boosting sustainable competitive advantage and sustainable manufacturing systems. In the future, one-touch fasteners may replace thread fasteners. The new die designs should lighten die sets and make centering adjustments easier.

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