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Research on Single Minute Exchange of Die （SMED） based on lean production

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Abstract

Lean production (LP) was created in the middle of the 20^{th} century. It is an appreciation to the production management approach of the Toyota in Japan. The technology is one of the implementing LP that single minute exchange of die (SMED). It is raised by industrial engineer Doctor Shigeo Shingo in 1969. SMED is the best method of reducing time of exchange die evidently. It is one of the key points of implementing LP in the company that multi-species and small batches through implementing SMED.

The LP is the best production organization and method of the manufacturing industry in the world. The paper briefly introduces the production and application of lean production, the structure system of lean production mode, and systematically summarizes the principle and implementation method of SMED technology. The SMED is based on the IE theory, from the perspective of traditional industrial engineering motion analysis and process analysis, to study the method of shortening the setup time, especially the internal setup time. Using the method research and operation measurement, the '5W1H' and 'ECRS principles' were used to analyze the setup process, and the existing problems were found, and the possibility of improvement was further explored.

The paper sums up the benefit on the implementation of the SMED through researching the setup process in the stamping workshop. A lot of saving and economic results have been achieved such as shorten the setup time, increasing productivity, improving company comprehensive competitiveness.

Key points: Lean Production (LP); SMED; Machine Changeover

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1 Background of SMED (Lean Production System)

Exposed to the global competitive pressure of continuously changing market conditions, more and more companies are facing the challenge of reducing the cost of production processes. Companies are increasingly addressing these challenges by designing and introducing individual, so called lean production system (LPS), which began in the automotive industry [1].

Figure 1 Structure of lean production

LPS has an open structure that allows individual selection and adjustment of methods based on the needs and circumstances within the particular enterprise. The use of methods requires constant review of efficiency and modifications if needed. The core of lean production is to eliminate all waste and keep improvement. This idea is both a management technique and a philosophy. Everything that does not generate added value is a waste, and it is everywhere. As a result, introducing lean production is necessary to eliminate waste which maximizes corporate profits, flexible manufacturing, and eliminating all waste in the production process, including time.

1.1 Characteristics of lean production

Lean production is people-oriented aimed to eliminate waste as the core at the most economical way in producing and manufacturing. When the customers propose their needs, according to the quantity required by customers, using the least resources to produce and provide the products as they need. Its implementation has greatly reduced waiting time, job switching time, finished product, work-in-process inventory, product failure rate, and shortened product production cycle. Its characteristics can be summarized as the following five aspects: Just-in-time Production, Total Quality Management, Teamwork, Concurrent Engineering, Zero defect. The specific description is as follows.

1) Just-in-time production

Lean production takes the end user's demand as the starting point of production, emphasizes the balance of logistics, and pursues zero inventory. It requires that the parts processed in the previous process can immediately be used in the next process. Relying on Kanban is the efficient method to organize the production line, that is, the Kanban will pass the information on demand from the forward to backward. And the form of Kanban is not limited whose key is to be able to transmit information. The beat in production can be manually intervened and controlled, however, it is important to ensure the balance of logistics in production. For each process, it is necessary to guarantee the right timing of the process supply. The production planning and scheduling are completed by the individual production units themselves, and the centralized planning is not adopted any more, but the coordination between the production units during the operation is extremely necessary.

In the process of exchange, the implementation of just-in-time production is mainly to prepare for mold change, convert the internal setup time as much as possible to the external setup time, strengthen the cooperation between the mold change workers, and shorten the mold change time.

2) Total Quality Management

Lean production emphasizes that quality is produced rather than tested. The quality control process in production guarantees the final quality. The quality inspection and control in the production process is carried out in each process, focusing on cultivating the quality awareness of each employee. Pay attention to the quality inspection and control in each process to ensure timely quality problems. If quality problems are found in the production process, according to the current situation, the production workers can immediately stop production until the problem is solved. As a result, it can be ensured that no failure occurs. To this end, the production line should have the function of automatic or manual control and stop. For the quality problems that arise, it is generally organized by the relevant technology and production personnel as a group to work together and solve as soon as possible. Ensuring the accuracy of the mold change operation, reducing the mold adjustment time during the mold change process, and reducing the invalid motion are important measures for implementing total quality management during the mold change process.

3) Teamwork

Every employee is not only the command of the superior in the work, but also the active participation, as the role of decision-making. The principles of the organization team are not completely divided according to the administrative organization, but mainly according to the relationship of the business. The team members emphasize that one is more versatile, more capable, and requires more familiarity with the work of other staff in the team to ensure coordination of work. The smooth progress of the team's work performance is affected by the internal evaluation of the team. The basic atmosphere of team work is trust, with a long-term supervision and control, while avoiding the audit of each step of work and improving work efficiency of the team. The organization is sometimes changing. Different teams are set up for different tasks, and the same person may belong to different teams.

The replacement of the mold is not a matter of an operator, but the whole team.

Collaborators should work together to complete the work, thereby reducing the labor intensity of individual workers and improving labor efficiency.

4) Concurrent Engineering

During the design and development of the product, the conceptual design, structural design, process design, final requirements, etc. are combined to ensure that the required quality is completed at the fastest speed. The work is completed by the relevant project team. Each member arranges his or her own work but can report information on a regular or timely basis and coordinate the problems that arise. Feedback and coordinate the entire project should be done based on appropriate information system tools, such as Computer Integrated Manufacturing (CIM) Technology. Parallelization of the auxiliary project process should be carried out at the same time during product research and development period.

The reason for the changeover time of some production companies is too long, mainly because there are no parallel and serial problems for handling operations. Not all mold changing operations must wait until the machine is stopped. Only the internal setup operation is converted to the external setup operation. As a result, the serial engineering can be changed into the parallel engineering aimed to shorten the mold change time and improve the production efficiency during the production process.

5) Zero Defect

The goal pursued by lean production is not ‘as good as possible’ but ‘zero defects’, namely the lowest cost, the best quality, no waste, zero inventory, and product diversity. Manufacturing products should be required like that, and the operations in the production process should also be the same. Ensuring the correctness and effectiveness of each operation is a prerequisite for implementing zero defect targets in production operations. This may be an ideal realm, but it is the never-ending goal of the company. Only in this way can the company remain invincible and always lead at the first place.

From that, we can see the so-called lean production method is a new type of production based on social needs and market demand, giving full play to people's role, using various modern management methods to effectively allocate and rationally use enterprise resources and strive to achieve maximum economic benefits.

1.2 Goal of lean production

Enterprises are social and economic organizations with the purpose of making profits. Maximizing profits is the basic goal of enterprises. In today's rapidly changing market, lean production adopts flexible production organization form, adjusts production in a timely and rapid manner according to changes in market demand, and relies on strict and meticulous management to achieve zero defect, zero inventory, zero waste and other sub-goals to achieve the basic goal of maximizing profits.

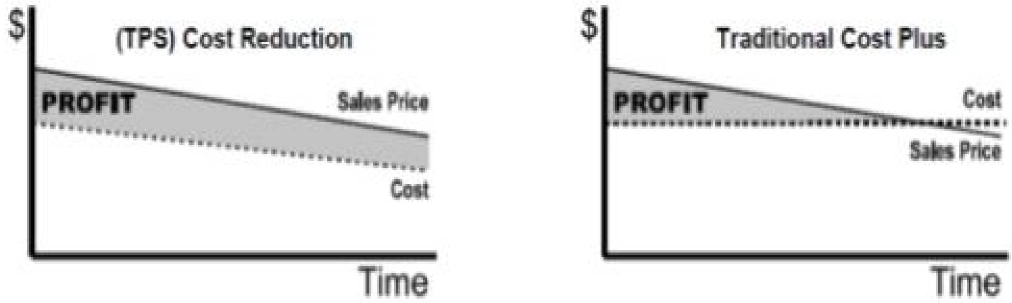


Figure 2 Lean production system compared with traditional production system

1) Zero waste

Eliminating waste is the unswerving pursuit of lean companies. It is generally believed that waste is ubiquitous in traditional enterprises. There are mainly seven forms of waste which are overproduction, waiting time on site, unnecessary movement of parts, redundant operation of operators, unqualified quality or rework, excess inventory, and other activities that do not add value. In addition, Jeffrey Lake believes that there is still an eighth form of waste, that is, unused employee creativity.

Regardless of the form of waste, the basic idea of implementing lean production in traditional enterprises is to eliminate all waste by continuously improving the production process, with the focus on eliminating all activities in the production process that cannot add value. This is also the main technical route and direction for traditional enterprises to implement lean production.

(2) Zero defect

Traditional production management rarely proposes zero defect targets. And the general company only proposes an allowable percentage of failure and an acceptable level of quality. Their basic assumption is that it is inevitable that a certain number of non-conforming products will be reached. In fact, the cost of producing redo parts is always caused by various errors, which will be dozens of times the cost of prevention. The goal of lean production is to eliminate all kinds of causes of non-conforming products at the source. At the same time, the demand should get the best level in each process. Pursuing zero defects will be realized on the basis of preventing work seriously in advance. In the meantime, we need to set up a goal that is the pursuit of 'the first time to do the right' and avoiding the 'wrong and then change' phenomenon.

3) Zero inventory

A production system full of inventory will mask various problems in the system. For example, equipment failure would cause downtime. Low quality of work would cause scrap or repair. And poor planning would cause production disconnection, etc. These problems have a great influence in a variety of inventory, so that contradictions passivated, problems are overwhelmed.

On the surface, production is still in balance. However, in fact, the entire production system may already be riddled with holes. What is even more frightening is that if the problems in the production system are ignored and insensitive in the long term, the sense of urgency and initiative will be lost. Therefore, the Japanese call the inventory 'the source of all evils', which is an unreasonable design of the production system, uncoordinated production processes, and poor production operations. So, they put forward the slogan of 'moving into zero inventory'.

1.3 Theoretical framework of lean production

Many experts and scholars have studied and discussed lean production. In summary, the theoretical framework for the study of lean production mainly includes ‘one goal’, ‘two pillars’ and ‘one foundation’.

(1) One goal

‘One goal’ is to produce at low cost, high efficiency and high quality so as to maximize customer satisfaction.

(2) Two pillars

The ‘two pillars’ are just-in-time (JIT) and personnel conscious. JIT production is market-led, producing the right quantity and high-quality products at the right time. JIT needs to be based on pull production and leveling system. The so-called pull production is based on the management of Kanban, using the ‘receiving system’. In other word, the subsequent process is based on the market’s needs to produce, the amount of work-in-progress in this process is taken from the previous process at the same amount of work-in-progress. As a result, the whole process pull production control system would be completed that would never produce one more product.

Leveling system means that the workpieces are artificially matched and sorted according to the processing time, quantity and variety before being pulled to the production system. Consequently, the workpiece flow pulled into the production system has the smoothness of processing time and ensure balanced production. At the same time, the mixed flow mode is realized in the variety and quantity, which can quickly respond to the needs of various varieties and small batches in the market and satisfy the different requests.

Personnel conscious is the organic cooperation between personnel and mechanical equipment. Problems of quality, quantity and variety would happen in the production line. The mechanical equipment is automatically shut down and has indications that anyone who finds the problem has the right to stop the production line immediately, take the initiative to troubleshoot and solve the problem. At the same time, quality management is integrated into the production process, and it becomes the independent behavior of each employee, turning all work into effective labor.

(3) One foundation

'One foundation' refers to continuous improvement. The improvement refers to the meaning that there is always some space for improvement to eliminate all waste. Improvement is the basis of lean production, and it can be said that there is no lean production without improvement. The production system of an enterprise always has space for improvement from part to whole. Only relying on the idea of eliminating waste and keeping improvement, the problems in production and management are improved in the way from easy to difficult, continuously improved and consolidated. Through unremitting efforts and long-term accumulation, it can ensure the continuous implementation of lean production methods.

1.4 Core and connotation of lean production

Lean thinking is the core idea of lean production. It includes a series of ideas such as lean production, lean management, lean design and lean supply, which requires the production organization to have a high degree of flexibility. At its core, it creates as much value as possible with less manpower, less equipment, and shorter time and smaller venues.

The flexible organization's production organization is flexible and adaptable. It can adapt to changes in production demand and organize multi-variety production in time to improve the competitiveness of enterprises. Lean manufacturing has a high degree of flexibility in terms of organization, labor and equipment.

The first is organizational flexibility. In lean production methods, the right to decision-making is decentralized rather than centralized in the chain of command. It does not use a static organizational structure based on functional departments, but rather is a dynamic organizational structure based on project teams.

Second is the flexibility of the labor force. When the market demand fluctuates, the labor force is required to make corresponding adjustments. The labor force of lean production is a cross-staff operator with multiple skills. When the demand changes, the number of operators can be adjusted to adapt to changes.

Finally, the flexibility of the equipment. Lean production uses moderately flexible automation technology, and the process is relatively concentrated. As a result, lean production is in the production conditions of small and medium batches, close to the high efficiency and low cost achieved by rigid automation in mass production mode, but it also has the flexibility while the rigid automation doesn't have.

The key to lean production is the management process, including the management optimization of personnel organizations, the streamlining of the middle management, the flat reform of the organization, the reduction of indirect production personnel, the equalization of production, the synchronization, and the implementation of the entire production process (including the entire supply chain). The quality assurance system pursues zero defect rate, reduces waste on any production process, and finally realizes pull-type on-time production.

Lean thinking requires companies to find the best way to determine value provided to customers, to clarify value stream of each product. As a result, product flows smoothly from the initial concept to the arrival of customers. And customers become the pullers of production and pursue excellence and perfection in production management. You can use a concise statement to summarize basic idea of lean production do everything possible to reduce unnecessary activities and try best to eliminate waste.

1.5 Superiority of lean production

Compared with traditional mass production methods and single-piece production methods, by establishing a pull system, you will able to deliver work only if there is actual demand which has better use of resources, the superiority of lean production methods in detail is reflected in the following aspects.

(1) New product development cycle

- the minimum can be reduced to 1/2 or 2/3.

(2) Work-in-process inventory

- the minimum can be reduced to 1/10 of the general level of mass production.

(3) The occupied space of the factory

- the minimum can be reduced to 1/2 under the mass production mode.

(4) Finished goods inventory

- the minimum can be reduced to 1/4 of the average inventory level in mass production mode.

(5) Product quality defects

- It can be reduced to 1/3 of the original.

(6) The required human resources

- Product development, production systems and other parts of plant can be reduced to a minimum of 1/2 compared to plants in a large production mode. When employees are focused on delivering value, they will be more productive and efficient, because they will not be distracted by unclear tasks.

2 Introduction of SMED

Nowadays, the single methods interdependencies in a complex and dynamic system of an enterprise can be modeled and simulated. As a result, a qualitative and quantitative analysis of interdependencies of the method Single-Minute Exchange of Die (SMED) in the field of lean production system will be used. Exchange time is one of the vital parameters used in any manufacturing industry and it is a form of necessary input to every machine or workstation. Since the setup processes are a collection of sequence-dependent changeover activities which are carried out before starting the production of any products.

Under the fierce competition, to better satisfy the needs and requests of the markets and customers, more and more companies adopt multi-variety and small-batch production methods [2]. At the same time, the companies begin to pursue customer characteristics of varieties, specifications and models. The distinctive features of multi-variety and small batches are diversified objects, diversified processing equipment, diversified process methods, continuous and intermittent process. Various diversifications make it necessary and significant for enterprises to respond quickly and to complete product orders with quality and quantity. What's more, it has a higher requirement about the time and money. Consequently, the production difficulty of the enterprise increases accordingly. Based on SMED of lean production, this issue has been studied to some aspects as followed.

- Embody the problem of setup
- Ensure product yield.
- Quantify the severity of the problem
- Simply the setup operation to reduce setup time, increase production flexibility, and achieve rapid response requirements
- Standardize setup process, such as optimize the setup process, reduce manpower, equipment waste, labor intensity, and solidify the setup operation process.

- Diversify the setup program is. Since it is to meet market demand, companies should have a variety of setup programs to face the different orders by using the most appropriate setup program to further reduce costs and maximize profits.

Nowadays, the market is increasingly demanding more customized products, which puts manufactures under pressure to reduce the product cost in order to survive in the highly competitive market. Therefore, companies must be able to produce a wide variety of products in a short period of time and consequently must provide for much more frequent die changes to reduce setup time [2]. Most companies are currently faced with a need to respond to rapidly changing customer needs, desires and tastes. To compete in this continuously changing environment, these companies must seek out new ways to stay competitive and flexible and simultaneously, enabling their companies to respond quickly to new demands.

2.1 Development of SMED

Firstly, we need to have a description of traditional changeover process. The following are the procedures of traditional changeover process.

1. The machine is shut down.
2. Old machine parts evacuated from the scene.
3. Mold changer and tool preparation
4. Cleaning table and mold fixture
5. Disassembling the old mold
6. Handling new molds, checking and maintaining
7. Assembling a new mold
8. Preparing new parts for trial production before the notice
9. Handling new parts to prepare for production
10. Operation adjustment

We can find some problems existing in traditional changeover activities.

The material starts to move after the machine is shut down.

- Finished products are sent to the next station
- Raw materials are removed after the equipment stops.
- New molds and various accessories are transported to the machine.

Defects and missing parts are only discovered when the machine is running.

- Defective parts shall not be repaired until mold change begins.
- Defective products shall not be found until the adjustment or the fine-tuning of equipment accessories is started.

After the machine is started, defective processing and fixture setting were discovered.

- After internal operation begins, the operator discovers the defect of the equipment.

Lack of standardized installation, adjustment procedures and technical requirements.

- Each modulator installs and adjusts according to their own experiences as they see fit because of the lack of standards.
- No two modulators install and adjust in the same way.
- Every shift feels last shift's adjustment is not up to par and needs to be readjusted.
- Some argue that the longer it takes to install and adjust, the better the products' quality will be.

We can find that the waste is everywhere during the traditional changeover process, including defect, overproduction, transportation, waiting, inventory, motion, processing.

As a result, we need to find a method to solve these problems and Single Minute Exchange of Die (SMED) is proposed [3]. SMED is one of the key points for implementing lean manufacturing to improve setup efficiency. Because lean manufacturing required small batch sizes and high product variation. A new method had to be developed to reduce the setup time during the changeover process. The SMED concept took its step at Toyo Kogyo's Mazda plant in Hiroshima, Japan, when its author, Shingo, conducted a production efficiency improvement study in 1950 [4]. The term refers to the theory and techniques for performing setup operations in less than 10 min. Although not every setup process can literally be completed in single-digit minutes, this is the goal of the system. Even it cannot reach goal, reduction is still a tremendous improvement. The preparation, adjustment and checking operation focus on making sure that the tools and materials will be used during setup process and they are available when the setup is scheduled. And idle time will not occur while the new setup material is being accumulated. The methodology was initially developed to improve stamping machine tool setups which often took multiple hours, typically 6 to 8 hours [5].

Figure 3 Stamping machine

The degree of exchange can be divided into different realms which is stated as followed.

Realm 1: No Concept of Quick Changeover

Realm 2: Single Minutes Exchange Die (SMED)

Realm 3: Zero Exchange Die

Realm 4: One Touch Exchange Die

Realm 5: One Cycle Exchange Die

Realm 6: No Need Exchange Die

The approach we research is the realm 2 which is sometimes known in the literature as Quick Change Over of Tools. SMED is a core technology in flexible manufacturing systems. Its core implements are the transition of the internal setup operation to the external setup operation so that we can continuously optimize and improve the internal setup time, and at the same time pursue realm 3 'zero exchange die'.

After that, Toyota's other process expert, Taiichi Ohno, also proposed the idea of setup time to the second. This technique was developed in the West until the 1980s when the West began to study Toyota's production methods. The publication of James Womack and Daniel Jones's book ‘The Machines for Changing the World’ spread the lean production methods and SMED to various industries. The theory and practice of SMED is constantly being improved.

The application of SMED methodology in various industries has been widely studied. The practical implementation of SMED technique in shortening the setup time in manufacturing industry about 11.9% and increasing annual production about 0.48%. And later for 8ton notching machine press setup process, SMED techniques was applied. Consequently, the setup time is reduced to 27.5% without any investment. What’s more, the SMED techniques also is applied in printing houses which decrease up to 73% of the total time.

SMED technique is a core technology in flexible manufacturing systems. It refers to a process improvement method that make possible to perform equipment changeover operations under 10 minutes [6]. SMED technique greatly improves setup process efficiency and provides a setup time reduction up to 90% with moderate investments. Setup operation is the preparation or post adjustment that is performed once before and once after each lot is processed.

2.2 Necessity of SMED

The ability of an enterprise to survive and develop has a great relationship with customer satisfaction. With the development of modern society, the requirements and requests of customers for products are increasing day by day, from the original price to the high quality of the products. And in order to satisfy the individual needs of customers, the products also should be completed on time and in good quality. Otherwise, in order to stand out in the market competition, companies must develop new products faster and better than their competitors and strive for the lead in time to create profits. In order to gain time, it is necessary to solve the problems of frequent setup operation and low equipment utilization caused by multiple varieties and small batches. This requires the use of SMED technology through standardization of molds, simplification of setup operations, and optimization of internal and external setup times to shorten the setup time [7]. As a result, the company has a competitive advantage. The figure 4 shows that the customer's needs are constantly changing and constantly improving. Correspondingly, the company's ability to survive and develop must also be improved accordingly. Achieving SMED is one of the key factors for companies to improve their core competitiveness.

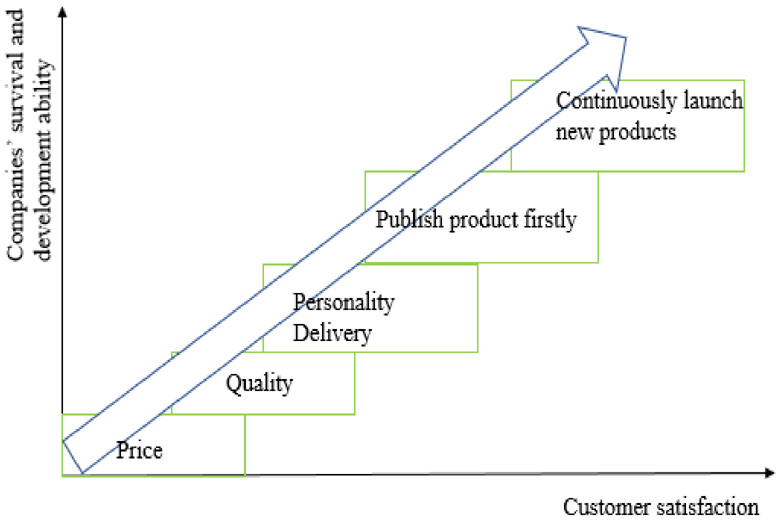


Figure 4 Relationships of customer satisfaction versus company’s survival and development ability

No matter what type of product, it must go through a series of processes to become the final product that meets customer requirements. However, it isn't any part of the entire process contributing to product value addition. What’s more, changing market demands brings high demands on flexibility and costs in part due to the transition from a seller’s to a buyer’s market and partly due to the globalization of markets. Companies have learned to identify and eliminate waste, increasing both production and quality.

Studies have shown that only 5% of all operations in a product's process can add value to the product, and the remaining 95% do not. This 95% includes such things as raw material defects, work-up, heavy work, product quality inspections, equipment downtime, mold change, inventory, material handling, and logistics shipping. Among them, the length of the exchange time is an important factor affecting the productivity of the enterprise.

Toyota has set SMED technique as one of the key factors to improve its competitiveness [8]. That is to say, the length of the setup time has become a direct reflection of whether a company's work efficiency is high or not. If a company changes its mold frequently and cannot shorten the time for setup, the competitiveness of the company must be weak. Mold replacement must be an organized and planned process. Once the exchange is formed, it can have a certain degree of repeatability. It can realize different setup processes for different varieties, ensuring that the setup process is completed in the shortest time and a qualified product is produced. If the company implements SMED, if it succeeds, it can achieve the following goals [9]:

- Improve the company's resource utilization.
- Implement SMED throughout the company.
- Produce new products quickly and accurately
- The setup time will be greatly reduced & production capacity will increase.
- While changing setup time, we must also ensure the quality of the product and even improve the pass rate of the product.

The number of exchanges operation will rise due to the increase in the number of product lines or the reduction of production volume. The time it takes to exchange is a loss to the factory. In order to reduce this loss, many people think of the solution is to increase the production volume of each product, and reduce the type of products, so that the average switching loss of each product will be reduced. In other words, the larger the batch size of production, the lower the cost of allocation exchanging. However, this approach only considers the reduction in the cost of the exchange itself but ignores the overall efficiency of the plant. For example, waiting for waste, waste of the defective products, too long production delivery time, turbid logistics, and so on. At the same time, if the output exceeds the market demand, the excess product must be stored in the warehouse. The storage must be related to inventory and related protection and management. Therefore, the larger the batch size of each production, the higher the cost of inventory.

As far as inventory costs are concerned, it is desirable to have as few batches as possible per production. The current market is based on multi-variety, small-volume, high-quality, short-delivery product competition. In this situation, shortening the exchange time is undoubtedly an effective measure to improve the productivity and competitiveness of enterprises.

To meet the production requirements of customers with multiple varieties and small batches of timely delivery, the preparation and production conversion of machinery and equipment must be completed in the shortest possible time to survive in an increasingly competitive market economy environment. At the same time, to implement the just-in-time production technology in lean production, it must be based on balanced production. A major difficulty in balanced production is the frequent exchange of production lines or molds. Whether the changeover of production processes can be achieved, that is, the level of switching efficiency and degree of standardization directly affect production efficiency and the stability of product quality.

To achieve balanced production characterized by ‘multi-variety, small batch’, it is necessary to shorten the production lead time to facilitate the rapid and timely production of various products. To shorten the production lead time, the setup time mainly the equipment replacement adjustment time must be shortened to minimize the production batch. Therefore, the improvement of handover and the shortening of the setup time are essential for the implementation of balanced production.

Mileham shows the relationship between design and methodology-based improvements on setup times and their effects on cost in figure 5.

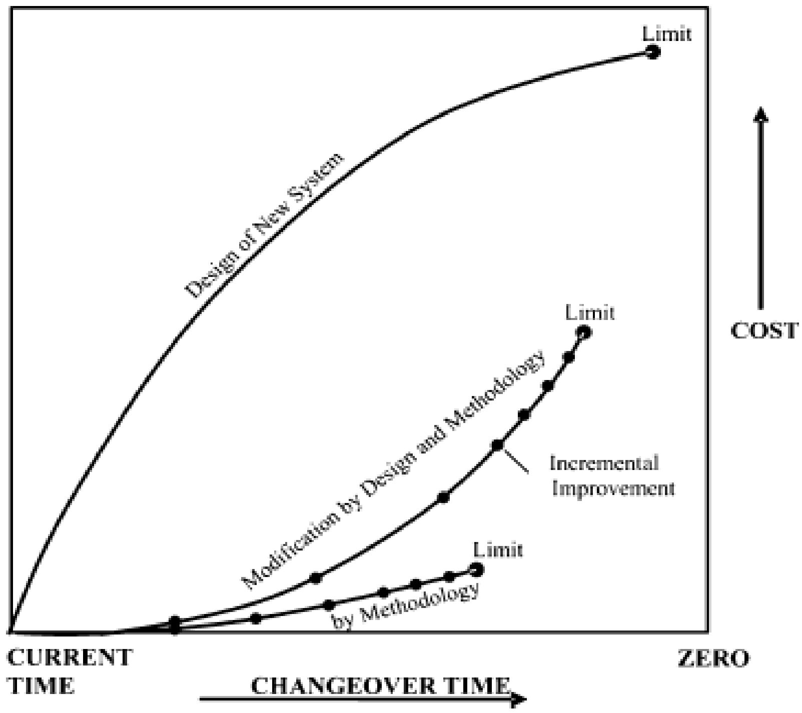


Figure 5 Setup time versus cost

Mileham shows that the relationship between setup time improvements and cost impacts in Figure 5. The ‘method-based’ improvements from Figure 5 are relatively inexpensive, but their ability to reduce setup time is low. On the other hand, the design cost of the new system is higher. However, significant setup time reduction can be achieved. According to Mileham, the reduction in setup time should be in a holistic approach to ensuring success and sustainability. As a result, it can be said that success and sustainability are performance indicators that can efficiently decrease setup time. Therefore, these two options must be evaluated on a sustainable basis. If a new system is designed to decrease setup time, it would be rather expensive as described above, however, it can be maintained more normally. It would work as expected and no alteration is observed.

On the other hand, modifying an existing changeover operation does not cost too much but is more difficult to sustain as methodology may change in time unless standardized and controlled. It must not be forgotten that preserving the success is as important as achieving it. Otherwise, all efforts to reduce changeover times may be worthless if one observes that the changeover times are rising to their previous value.

2.3 Effect of setup time on workstation or lines

When we consider the effective process time, the natural variability must be taken into consideration. The natural variability of the process time is generally related to workers, but it could also be related to other sources, such as setup, tool change, etc.

For example, the workstation is a milling machine and performs the tasks on the engine head, but the whole process time is 6 minutes, but the tools must to be replaced every 50 heads with a setup time of 20 minutes.

$$t_e = t_0 + \frac{t_s}{N_s} = 6 + \frac{20}{50} = 6.4\text{min}$$

$$\sigma_e{}^2 = \left(\frac{c_0{}^2}{t_0{}^2}\right) + \frac{c_s{}^2 + t_s{}^2}{Ns} + \frac{(Ns-1)t_e{}^2}{Ns^2} = 51.86min^2$$

$$c_e{}^2 = \frac{\sigma_e{}^2}{t_e{}^2} = 1.266$$

t0=6min
ts=20min
Ns=50

WORKSTATION

$$\text{u} = r_a t_e = 0.667 < 1$$

$$\text{TH} = r_a = 0.104pcs/min$$

$$\text{CT} = \left(\frac{1}{2}\right)(c_a{}^2 + c_e{}^2)\left(\frac{\text{u}}{1-\text{u}}\right)t_e + t_e = 22.15\text{min}$$

$$\text{WIP} = \text{TH} * \text{CT} = 2.307\text{pcs}$$

We can find that if the setup time is too long, as a result, the effective process time will increase. And variance of the effective process time would rise. Consequently, the cycle time and work in process will increase which means that there will be more and more pieces in the workstation that need to queue for a long time. In conclusion, when setup time can be shortening, the evaluation of the workstation and lines would be improved a lot.

Generally, all the variables are classified by their characteristics into the state variables, flow size or auxiliary variables. The flow chart is shown in figure 6. The resulting system of equations should depict the dynamic system behavior of a real system as closely as possible [10].

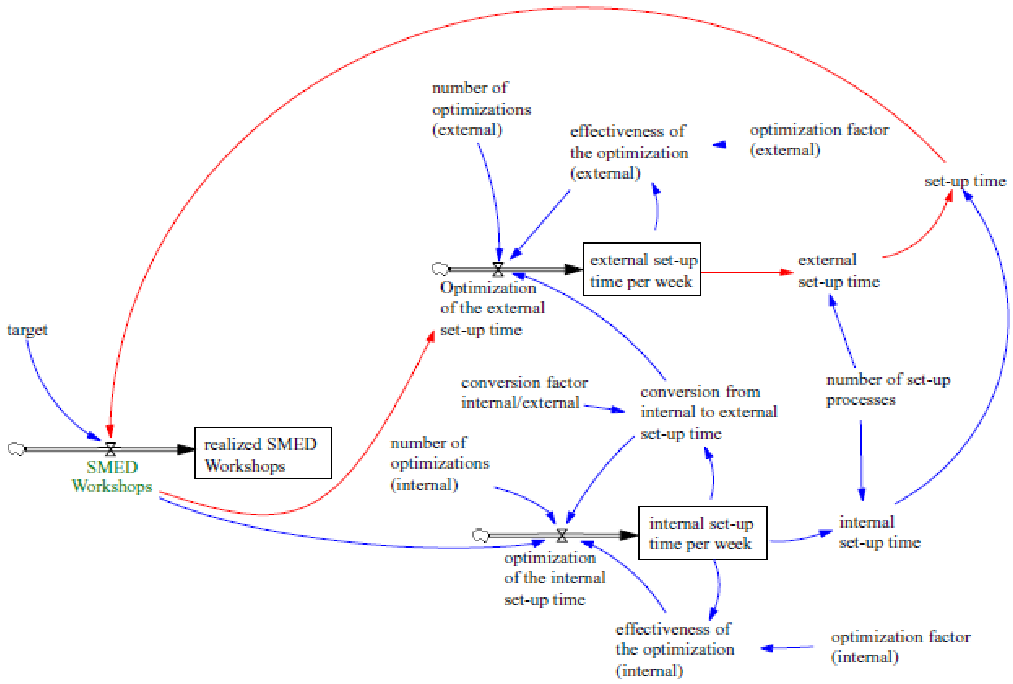


Figure 6 Model of the SMED methodology

The rate variable SMED workshop (WS_{SMED}) introduces the temporal variation of the number of SMED applications. And it would result from the comparison of the setup time (SUT) with the target time (TT). A positive difference results in the need for action to carry out a SMED workshop [10]:

$$WS_{SMED} = \begin{cases} 1: \mathrm{SUT} - \mathrm{TT} > 0 \\ 0: \mathrm{SUT} - \mathrm{TT} \le 0 \end{cases}$$

The external setup time $\mathrm{OSUP_{ex}}$ is also a rate variable. The conversion from internal to external setup time ($\mathrm{C_{SUTin-SUTex}}$) counteracts the reduction in the external setup time by the product of number of optimization ($\mathrm{O_{ex}}$) and the effectiveness of optimizations ($\mathrm{E_{ex}}$). The change of the external setup time arises in the present model out of the context.

$$\mathrm{OSUT_{ex}} = WS_{SMED} * (\mathrm{C_{SUTin-SUTex}} - O_{ex} * \mathrm{E_{ex}})$$

The division of the external setup time per week ($SUTW_{\mathrm{ex}}$) with the number of setup procedures (SUP) gives the external setup time per procedure ($\mathrm{SUT_{ex}}$)

$$\mathrm{SUT_{ex}} = \mathrm{SUTW_{ex}}/SUP$$

The internal setup time ($\mathrm{SUT_{in}}$) added to the external setup time per procedure gives the setup time (SUT). The control loop closes with the change of the setup time.

$$\mathrm{SUT} = \mathrm{SUT_{ex}} + \mathrm{SUT_{in}}$$

2.4 Indicator of setup (OEE)

The OEE data is used to understand the impact of the equipment improvements. The OEE measures the overall efficiency of monitored installations (cell, machine, production line, systems) giving indicators of the gaps between the real performances versus the expected target [11]. The OEE of a production system is measured by analyzing all its losses. The OEE can be measured on systems during production phases and not for target preparation.

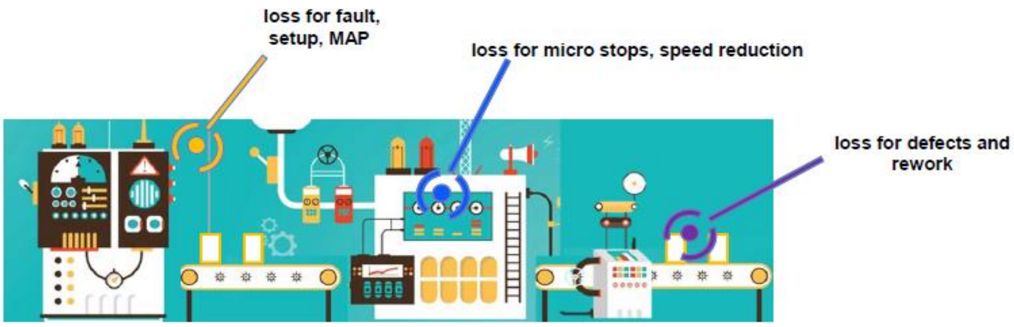


Figure 7 Losses during the production process

The OEE measures the overall efficiency of systems through the calculation of three factors that represents the three main loss families: technical availability, performance, quality. An OEE score of 100% means you are manufacturing only Good Parts, as fast as possible, with no Stop Time.

*OEE=(A) Availability * (P) Performance * (Q) Quality*

Availability takes into account Unplanned and Planned Stops. An Availability score of 100% means the process is always running during Planned Production Time.

$$A = \frac{Actual\ Running\ Time}{Planned\ production\ time} \times 100$$

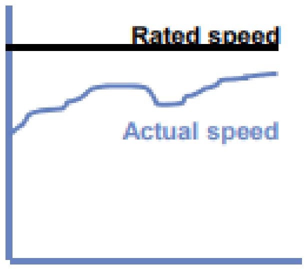


Figure 8 Rated speed versus actual speed

Performance takes into account Slow Cycles and Small Stops. A Performance score of 100% means when the process is running it is running as fast as possible.

$$P = \frac{\text{Actual output}}{\text{Target output}} \times 100$$

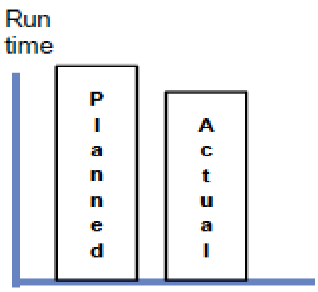


Figure 9 Actual output versus actual output

Quality takes into account Defects (including parts that need Rework). A Quality score of 100% means there are no Defects (only Good Parts are being produced).

$$Q = \frac{\text{Good output}}{\text{Actual output}} \times 100$$

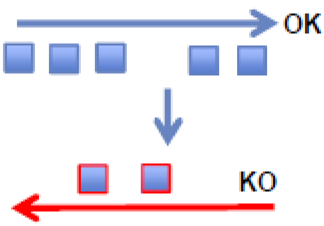


Figure 10 Good output versus actual output

Consequently, the downtime losses or machine stop are used to calculate the availability factor, the speed losses determine the performance efficiency of the equipment, and the quality losses are incorporated to calculate the quality rate. The details are followed.

<u>Downtime losses or machine stop (impact on A- availability)</u>

1) Faults:

Sudden and unexpected equipment faults or breakdowns are an obvious cause of loss, since an equipment faults means, that the machine is not producing any output.

2) Change of type:

A changeover is determined by a planned variation in the production plan or replacing tools / dies due to wear and tear or being broken.

3) Set-up and calibration.

4) Tool change:

Most machine changeovers require some period of shutdown so that internal components can be exchanged or adjusted. The time between the end of last good product produced and the first good product produced of the following production run is downtime. This downtime loss often includes substantial time spent making adjustment until the machine gives acceptable quality on the required product.

5) Start-up / Stop:

The start-up loss occurs for the period of time preparing the line for starting up and running in the equipment until conditions have been stabilized. Yield losses occur when production is not immediately stable at equipment start-up, so the first product do not meet specifications. This is a latent loss, often accepted as inevitable, and it can be surprisingly large.

<u>Loss of efficiency (impacts on P - Performance)</u>

6) Micro stops and waits:

When a machine is running and stop / starting frequently, it will lose speed and obstruct a smooth flow. The idling and stoppages in this case are not caused by technical faults, but small problems such as product that block sensors or get caught in chutes. Even though the operators can easily correct such problems when they occur, the frequent stoppages can significantly reduce the effectiveness of the equipment.

7) Cycle time slowed down:

Reduced speed operation refers to the difference between the actual operating speed and the equipment's designed speed (also referred to as theoretical). There is often a gap between what people believe is the 'maximum' speed and the actual speed designed (theoretical) maximum speed. The aim is to eliminate the gap between the actual speed and the designed speed. Significant losses from reduced speed operation are often neglected or underestimated.

Loss of quality (impacts on Q - Quality)

8) Defects and rework:

Loss occurs when products do not meet quality specifications, even if they can be reworked to correct the problem. The goal should be zero defects to make the product right first time, every time.

However, there are 2 largest losses not affecting OEE factors.

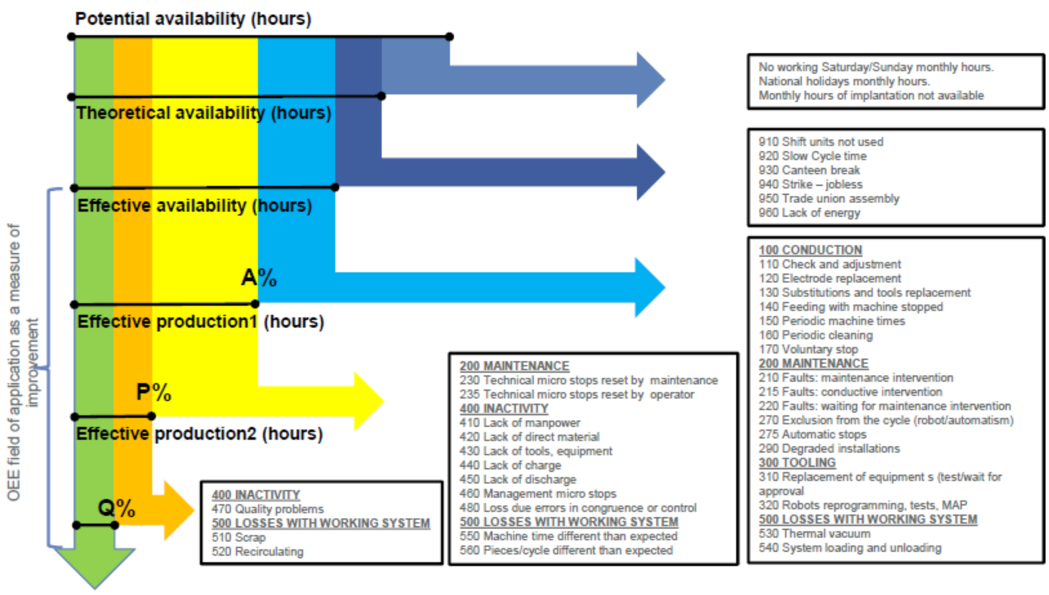
Equipment performance loss

a. Stop for closure of the plant:

Other scheduled downtime losses due to no loading, no material and labor shortage.

b. Unused time:

this is the period of time during the week where the equipment is not staffed due no weekend working, bank holidays or factory shutdown having an impact on loading time.



$$OEE = A\% \ x \ P\% \ x \ Q\% = \frac{Eff.Prod.1}{Eff.Avail.} \ x \ \frac{Eff.Prod2}{Eff.Prod1} \ x \ \frac{Eff.Prod3}{Eff.Prod2}$$

Figure 11 OEE calculation example

As already mentioned, OEE is a simple metric that concludes three contributive factors of a given equipment efficiency. The simplest formula to calculate OEE is the ratio of fully productive time to planned production time. Fully production times represents the time spent to produce only good parts at ideal cycle time and no stops.

$$\mathrm{OEE} = \frac{\text{Good Parts Produced} \times \text{ideal Cycle Time}}{\text{Planned production time}} \times 100$$

OEE calculation through three factors $A \times P \times Q$ allow to have a better understanding of which kind of losses are affecting the production.

$$\text{Availability} = \frac{\text{Run Time}}{\text{Planned production time}} \times 100$$

$$\text{Performance} = \frac{\text{Total Parts Produced} \times \text{ideal Cycle Time}}{\text{Run time}} \times 100$$

$$\text{Quality} = \frac{\text{Good Parts Produced}}{\text{Total Parts Produced}} \times 100$$

OEE is time depending and should be measured periodically on sufficient period of time to have a representative average value.

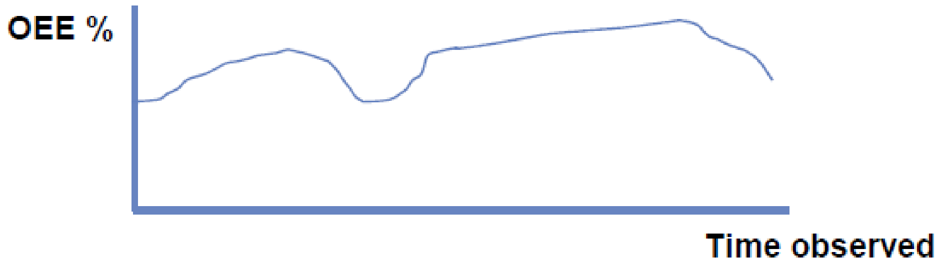


Figure 12 OEE% versus time observed

2.5 Importance of SMED

Setup time would determine the downtime, capacity, product quality and, to some extent, costs. The SMED technique is an important lean tool to reduce waste and improve flexibility in manufacturing processes which allows lot size reduction and manufacturing flow improvements. SMED technique would reduce the non-productive time by streamlining and standardizing the operations for changing tools, using simple techniques and easier applications. However, the setup process does not give the specific actions to implement which can result in overlooking improvements. To overcome this, common statistical and industrial engineering tools can be integrated in the SMED technique.

It has become a direct reflection of the efficiency of factory and the quality of management. It is also a direct reflection of the high and low production costs of the factory. And it is one of the ways for enterprises to implement lean production. What's more, it can be easily shown that there is a direct relationship between lot sizes and number of setup times. The shorter the setup time, the smaller the lot size. Therefore, to some extent, it can be produced in an efficient way and the less important the actual order size.

In today's rapid setup of industrial products, there are fewer and fewer opportunities for a company which would last for a few months. If the setup process is frequent and the setup time cannot be directly and effectively shortened, the competitiveness of the enterprise is not competitive.

SMED is an organized process. It can shorten the setup time when the production line produces different products, improve the repeatability of the conversion, ensure the successful mold change in the shortest possible time and produce qualified products. It can encourage producers to reduce production volume and reduce inventory levels without affecting normal production operations. The success of SMED can bring about the following beneficial changes.

1. Reduce inventory quantity, save inventory space, increase inventory turnover rate
2. Reduce scrap and repair
3. Reduce handling, Use smaller and fewer totes
4. Reduce production batches and adapt to the production needs of customers
5. Improve safety and hygiene level of the production line
6. Implement the idea of lean production into specific operations.
7. Simplify production schedule to help balance production and implement just-in-time production methods

3 Principles and related methods

3.1 Principle of SMED

The practice of SMED is mainly based on the IE theory, from the perspective of traditional industrial engineering motion analysis and process analysis, to study the method of shortening the setup time, especially the internal setup time [12-14].

1. Do not move your feet

The exchange operation is mainly dependent on the action of both hands, and the foot must reduce the chance of moving or walking. Therefore, the props, mold and cleaning tools that must be used when exchange happens must be placed on a dedicated trolley and sorted out to reduce the time of search. The moving line of the mold or the exchange items must also be designed to be easy to enter and exit. And the sequence and order of setup operations should be rationalized and standardized.

2. Parallel operation

The so-called parallel operation means that two or more people work together to perform the exchange operation. And the parallel operation is most likely to obtain the effect of shortening the internal setup time immediately. It takes an hour to complete for a person to do the exchange jobs. If it can work together by two people, it may be completed in 40 minutes or 20 minutes. Then the entire exchange process is reduced from the original one hour to between 20 minutes and 40 minutes.

The labor time required for parallel operations may increase, invariant or decrease, which is not the focus of consideration. Because the other effects obtained by shortening the setup time are much larger than the labor cost. However, this point is much easier for the general person to ignore. When working in parallel, the coordination between the two persons must be skillful, especially in the safety. It cannot cause accidental injury due to negligence.

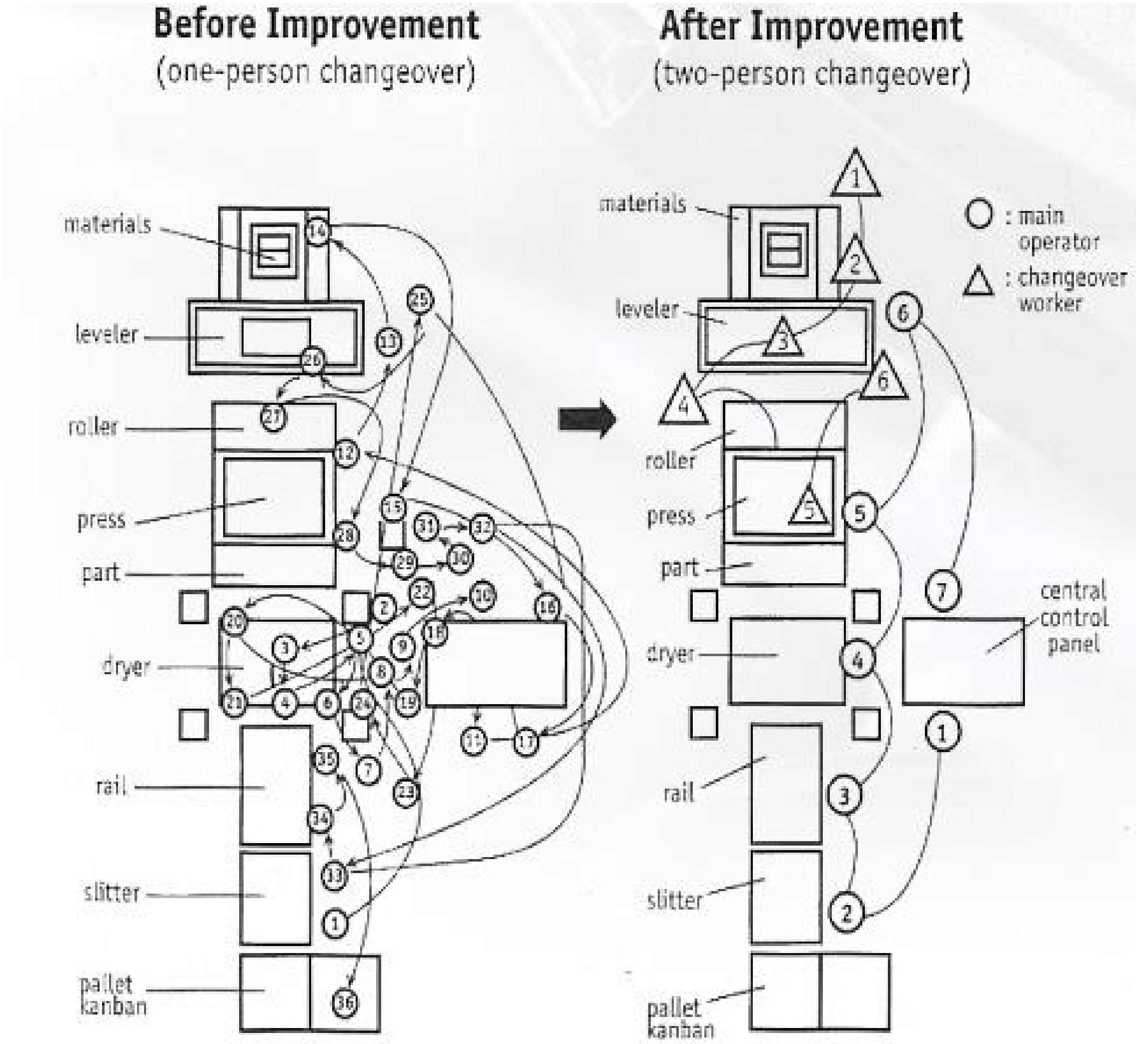


Figure 13 Difference between one person and two-person changeover

3. Special props

The so-called tools are general-purpose appliances. And the props are special-purpose appliances for special purposes. The setup operation is to use the props as much as possible without using tools. Because the props can improve setup efficiency and shorten the setup time. In addition, the measuring device should also be props. So, the gauge or the grid can be used to read the numerical value instead of measuring ruler or the meter. The most important point is to try to reduce the variety of items so that we can reduce the time to find, pick and place.

Figure 14 Measuring tool -ruler

Figure 15 Measuring tool - gauge

4. Remove the screw

When doing the exchange operation, the most common method to fix the mold is the screw. The use of screws is of course necessary, but the action of loading and unloading screws usually takes up a lot of setup time. If you observe closely, you will find that there are too many places where need screws to fix. For example, only 4 screws are enough, but 6 are used. The number of turns of the screw is too much, and it takes lots of time. In fact, the screw really tightens when the last lap is finished. Therefore, the best countermeasure for improvement is to eliminate the fixing method using screws. So, we can use bolts, levers, intermediate clamps, card socket and shaft cam lock or positioning plate.

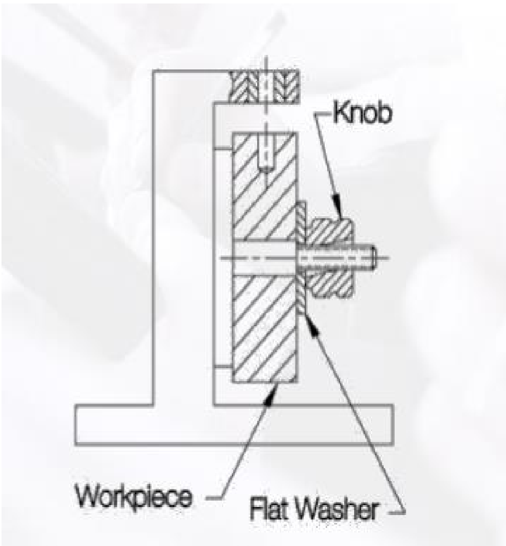


Figure 16 Fixing tool - knob

Figure 17 Fixing tool - clamp

5. One turn

When it is necessary to use bolt or screw in some cases, try to reduce the time for tightening and removing the screws. It is an improvement goal to be able to achieve the function of locking without removing the bolts and screws. The main method can be tightened or relaxed with only one rotation.

For example, a C-shaped open washer can be placed under the nut. After the nut is loosened, the C-type washer can be removed from the opening for complete relaxation. When it is tightened, it will be reversed. And only one rotation can be used to achieve the purpose of tightening. In addition, this can also be achieved by means of a cucurbit hole. The second method is to fix the height of the locking part. However, in one hand, we need to notice that if the locking part is too high, it should be cut to the standard height. In the other hand, if the locking part is too low, it can be added with the block to reach the standard height. Once the height of each mold locking part is standardized, that is to say, the tightening position of the nut will not change. As a result, the number of rotations of the locking and relaxing has been greatly reduced, and of course, the setup time will be reduced in some extent.

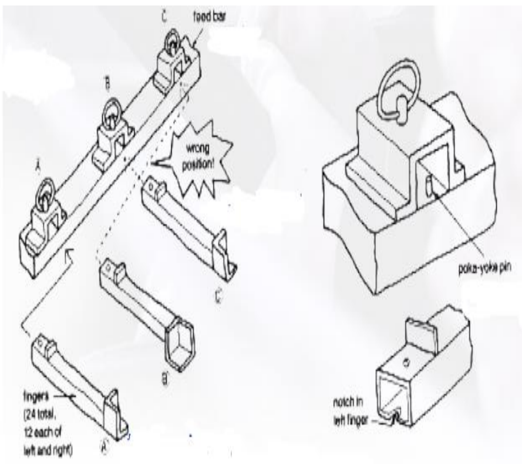


Figure 18 Auxiliary tool to one turn (1)

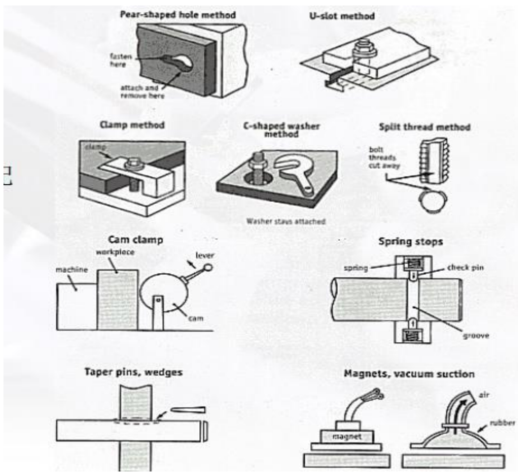


Figure 19 Auxiliary tool to one turn (2)

6. Standardization

The setup operation necessitates the replacement of different molds or working conditions due to different products. Therefore, it is necessary to make adjustment actions and set new standards. The adjustment action usually takes about 50%-70% of the entire setup time. And the length of the adjustment varies greatly.

When the luck is good, it is adjusted at once. However, if the luck is bad, it would take tens of minutes or even a few hours. To eliminate the waste of adjustment, you must grasp the standard of immobility in the method. In other words, the standard that has been set on the machine, do not change because of the replacement of the mold. In practice, the adjustment operation of the internal operation can be moved to the external operation, at the same time, the operation should be set and performed in advance.

Figure 20 Tool standardization (1)

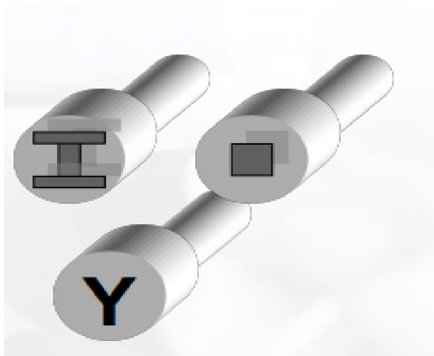


Figure 21 Tool standardization (2)

7. Preparation

Preparation is a job that belongs to external operation. If the external operation is not done well, it will greatly affect the smooth progress of the internal work, and the setup time will become longer. For example, if the external operation is not fully prepared, the required props or mold errors are not found in the internal operation, it is necessary to temporarily pause to find the right props or trim the mold, resulting in a long setup time. Therefore, the movement of the external operation should also be improved to standardize it.

A special trolley can be set up which is put all the required molds, props, mold change schedules and related equipment during exchange process so as to reduce the time of individual search and handling. The place where the mold is placed should also be clarified. And the storage place should be marked with a meaningful numbering method. The storage of utensils, instruments, and props should not be placed in a functional manner, and it is better to place and set a special box for different products or molds. Set up a checklist to assist in the completeness of the equipment required for the checkpoint, compile a standard switching schedule, and distinguish the operations and implement the grouping.

Figure 22 Trolley to put tools (1)

Figure 23 Trolley to put tools (2)

3.2 Methods applied to analysis

The technical system for SMED is mainly work research. The work research includes method research and operation measurement. This technology analyzes '5W1H' and 'ECRS' principles for each program to find problems and improve them.

Method research is a research technology that standardizes operations. It includes process analysis, job analysis, and motion analysis. The three analyses range from coarse to fine and from general to local. The specific concepts of the three analyses are as follows.

- Process Analysis: Analyze the entire work process or a management process.
- Job Analysis: Analyze work on the same job site.
- Motion Analysis: Analyze the process into basic units.

Among these three analyses, motion analysis includes analysis of action elements and action economy.

Action elements of motion analysis

Analysis of action elements mainly used to eliminate invalid actions, simplify operation methods, promote effective actions, and reduce worker fatigue. Action elements are mainly divided into three categories. The first type is the action necessary to complete a job, and the second type is the action that causes the first type of action to have a slow tendency. The third type of actions that are completely ineffective are actions that are to be eliminated.

The table1 1 is the three types of actions mentioned at below. The first type of action is a necessary action, but for moving, assembly, disassembly should be reduced as much as possible. The second type of action is the action that slows down the first type of action. It also should be reduced as much as possible. The third type of action is pure waste and should be eliminated.

Action economy of motion analysis

The principle of action economy is that people get the maximum work effect with the least amount of labor when operating. It can be summarized as 4 points.

1. Both hands should be used at the same time, avoiding one hand idle.
2. Reducing the number of action units, avoiding unnecessary movements.
3. Trying not to have systemic activities, avoid or minimize body movable.
4. Creating a comfortable working environment that reduces or avoids unreasonable work postures such as bending over.

Table 1 Three type of motion actions

the first type	empty hand	Assembly, disassembly, and movement during operation are actions that are to be minimized
	grab	
	move	

	assembly	
	disassembly	
	use	
	defense	
	examine	
the second type	position	minimize the occurrence of the second type of action
	search	
	turn up	
	select	
	think	
	pre-position	
the third type	maintain	invalid action-- try to eliminate it completely
	delay	
	wait	

3.2.1 5W1H _Method

5W1H is the abbreviation summarizing the following six questions: What? Who? Where? When? Why? How? This method consists of asking a systematic set of questions to collect all the data necessary to draw up a report of the existing situation with the aim of identifying the true nature of the problem and describing the context precisely and detailly.

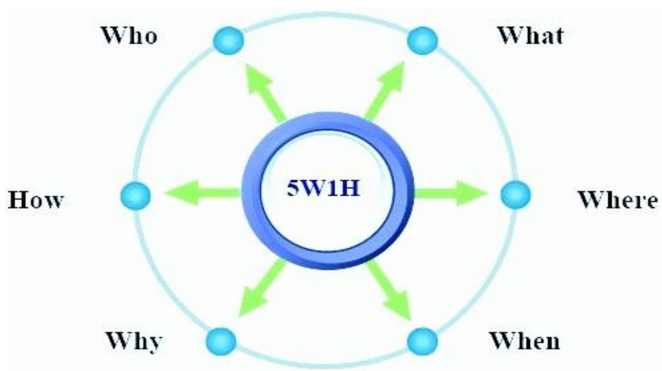


Figure 24 5W1H method

The 5W1H method breaks down into three main stages.

1. Describe the initial situation.
2. Determine the key factors and priorities them.
3. Propose fitting and importantly effective actions.

What?

- Explanation: Description of the task, the activity, the problem, the project purpose.
- Targets: Purpose, actions, procedures, machines, etc.
- Sample questions: What is the problem or risk? What is the situation? What are the product characteristics? How does the service work?

Who?

- Explanation: Determine stakeholders involved, the people responsible or affected.
- Targets: Managers, customers, suppliers, victims, those directly involved, etc.
- Sample questions: Who is in charge? Who found the problem? Who will be asked to do the work?

Where?

- Explanation: Describe the place or location involved.
- Targets: Premises, workshop, workstation, etc.
- Sample questions: Where does the problem apply? Are the premises easy to access? On which machine is the problem located?

When?

- Explanation: Determine the time when the situation took, takes or will take place.
- Targets: Dates, duration, frequency, etc.
- Sample questions: How long does it take? When is the installation date? How often does the problem arise?

Why?

- Explanation: Describe the motivation, the objective, the justification or reason behind a method of working.

- Targets: Goals, purposes, justification, etc.
- Sample questions: What is the targeted objective? Why was this training or this equipment chosen?

How?

- Explanation: Determine the way to proceed, the steps and method employed.
- Targets: Procedures, organizational methods, actions, means and techniques, etc.
- Sample questions: Under what conditions or circumstances? How is the department organized? What are the methods used? What resources are employed?

3.2.2. ECRS Principles

ECRS principles can help people find better performance and process methods. Based on the 5W1H analysis, the direction of improvement of process flow and conceive new working methods can be found instead of the current working methods.

Eliminate

In this step, it's important to identify steps that can be quickly eliminated. Where possible, eliminate details of work. Questions such as 'what is done', 'whether it is necessary and why' are passed, and those who are not necessary can be eliminated. There is no basic cause that adds value can be eliminated at once. Eliminating unnecessary processes, operations, and actions is an improvement that does not require investment.

Combine

When work cannot be eliminated, then seek to combine them to save time and simplify. Normally it is thought more efficient to break down a process into many simple operations. But this division of labor may have been carried too far resulting in excessive handling of the materials, tools and equipment. Such situations can be identified and corrected by simply combining two or more operations by making some changes in the operations. In this step, the combine phase addresses the Who, Where, and When. For example, combining some processes or actions, or different operations performed by multiple people in the different locations are replaced by one person or one device.

<u>Rearrange</u>

When production is scaled up, the original method may still be retained even though it can be improved. For this and other reasons it is desirable to examine and question the order in which the various operations are performed. It can be rearranged according to the questions of "Who", "Where", "When", so that they can have the best order, remove the duplication and make the work more orderly.

<u>Simplify</u>

After the steps of Eliminate, Combine, Rearrange are done, the step Simply is taken up. A good rule of thumb regardless of the situation is to simplify anyway. After the above-mentioned necessary work, you can consider whether you can use the simplest methods and equipment to save manpower, time and expenses.

That is, by asking questions, the first consideration is to cancel unnecessary work (process, action, operation). Secondly, some processes or actions are combined to reduce the processing procedures. Thirdly, the arrangement of the workbench, the machine, and the storage and transportation office is re-adjusted to reduce the distance of handling. Among them, you may want to change the order of operations or inspections to avoid duplication. Finally, you can replace complex equipment and tools with the simplest equipment and tools, or replace complex and heavy movements with simpler, labor-saving and time-saving actions.

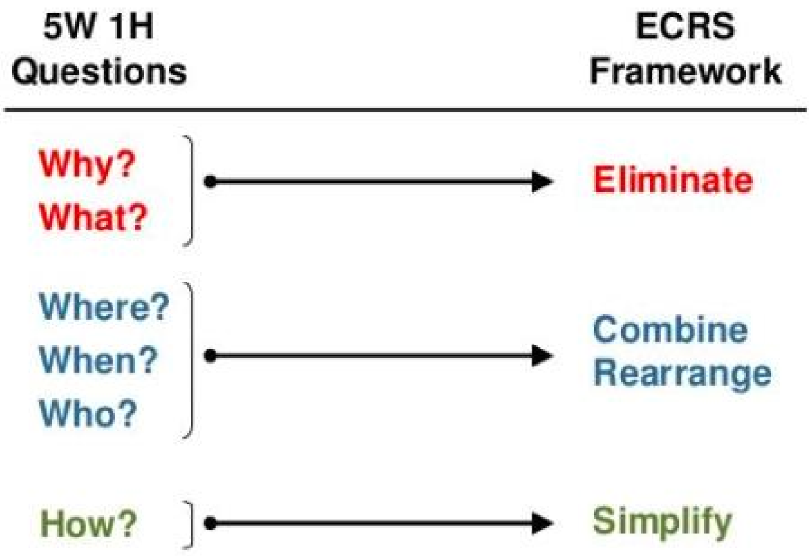


Figure 25 The relationship between 5W1H method and ECRS principles

3.2.3 Value stream mapping

The most effective way to achieve the goal that shorten the setup time is to increase the production flexibility through smaller batches production. However, this type of production would lead to a little increase in the setup frequency. As a result, the companies must find a proper and right way to reduce setup time and eliminate unnecessary waste as well as limiting some activities without real added value. In order to identify, qualify and minimize major wastes, it is important to use the value stream mapping tool (VSM) [15-16].

Value stream mapping template automatically calculate your optimum batch sizes for you. VSM is a special type of flow chart that uses symbols known as 'the language of Lean' to depict and improve the flow of inventory and information. Its purpose is to provide optimum value to the customer through a complete value creation process with minimum waste in designing, building, sustaining.

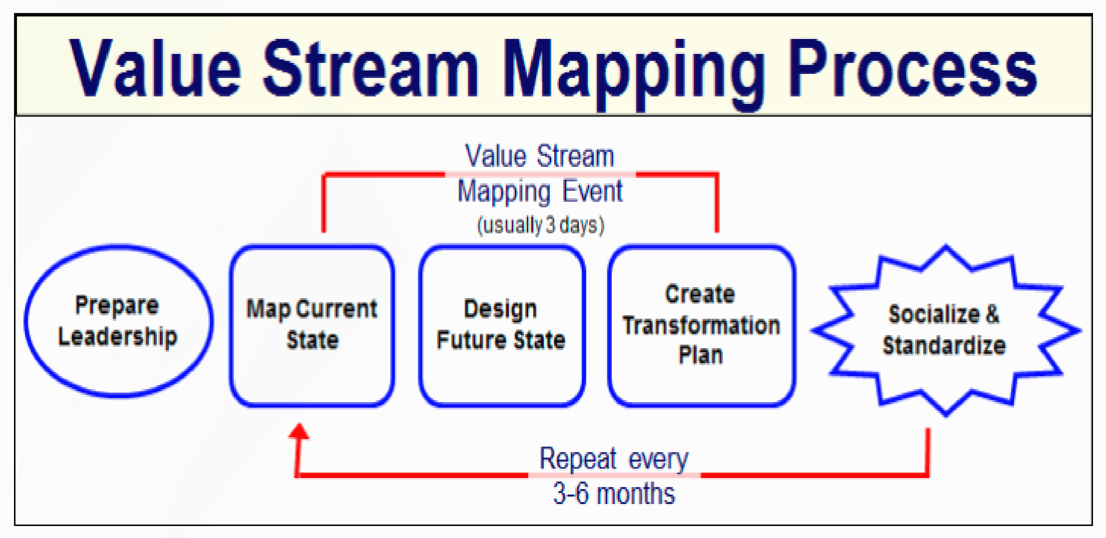


Figure 26 Value stream mapping process

Before use the SMED method, firstly, we can use the value stream map (VSM) to remove the different kinds of waste in production and improve the current situation. These two methods are often used together which are the lean tools to get higher productivity, less stock, improved quality, reduced lead time, greater flexibility and smaller lot sizes.

3.2.4 A3 methodology

A3 methodology is a structured problem-solving and continuous-improvement approach [17]. This methodology was firstly developed by Toyota Motor in the 1960s and later embraced by proponents of Total Quality Management, Six Sigma, Lean and other systematic approaches to continuous improvement. And A3 methodology shows the essential information about the problems. It provides a simple and strict procedure that guides problem solving by other workers. And it should be noticeable in a short space of time. The approach typically uses a single sheet of ISO A3-size paper which is the source of its name.

Generally, it could be summarized in 7 elements:

1. Logical thinking - A3 represents a step-based thinking process.

2. Presentation information in an objective way - There are no hidden agendas here.
3. Results and processes - Sharing what end results were achieved as well as the means of achieving them.
4. Share only essential information and put it into a visual format whenever possible.
5. Whatever actions are taken, they must be aligned with company's strategy.
6. Develop a consistent perspective that is adapted across entire organization.
7. Develop a structured approach to problem-solving.

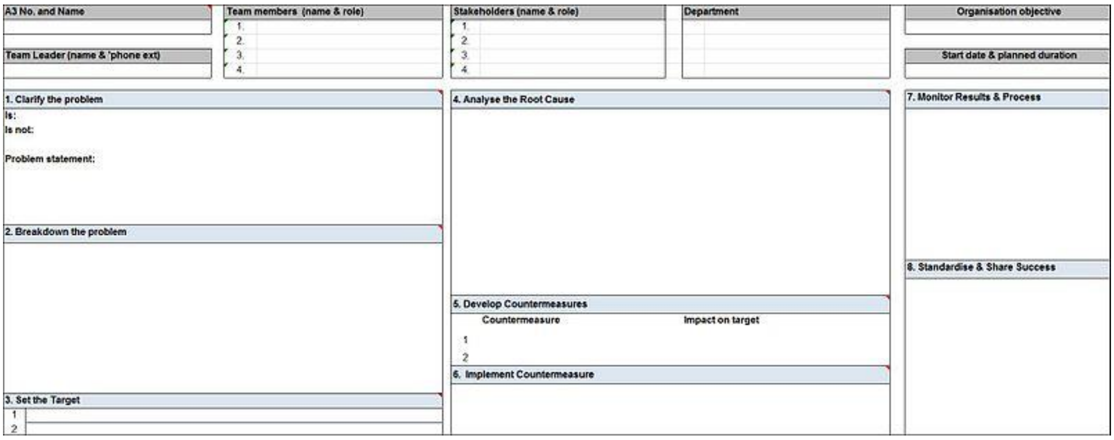


Figure 27 A3 methodology example

4 Procedure of setup operation

4.1 Composition of setup time

The SMED system is a theory and set of techniques that make it possible to perform equipment set-up and changeover operation in less than 10 minutes. SMED improves changeover process and provides a changeover time reduction up to 90% with moderate investments. Changeover operation is the preparation or after adjustment that is performed once before and once after each lot is processed. The exchange time refers to the time from the end of the production of the previous product to the production of the first of the next qualified product.

There is another concept related to this, that is, the line changing efficiency $\eta = 1 / T$. It can be seen from the expression of η that the larger the changeover time T, the lower the change efficiency η, and the more time the enterprise wastes on the operation of changing, debugging, etc., which cannot create additional value [18-20].

<u>Composition of exchange time</u>

The exchange process is mainly composed of four parts:

- setup preparation (run)
- setup operation (stop)
- placement adjustment (stop)
- adjustment again (run)

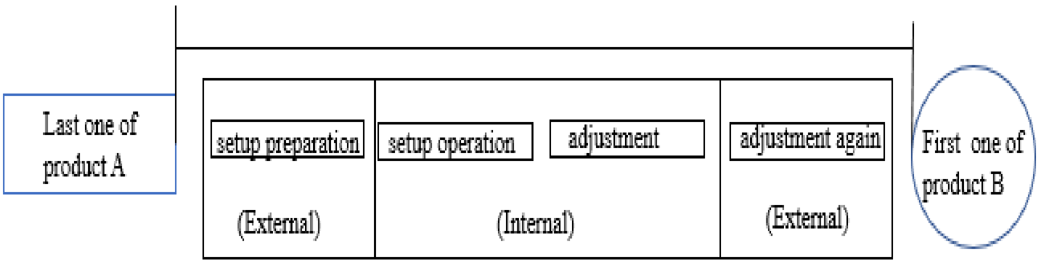


Figure 28 Process of the setup operation

The changeover operation has its time characteristics, because some operations can only be operated when the machine or process is stopped, while others can be operated while the machine or process is running. According to this feature, the setup time can be divided into 'internal setup time (stop)', 'external setup time (run)' and 'adjustment time'.

Internal setup time

It refers to the time when the exchanging operation cannot be performed without stopping the machine. For example, removing the workpiece from the machine, removing the used mold, cleaning the surface of the workpiece, installing a new mold, and placing a new workpiece.

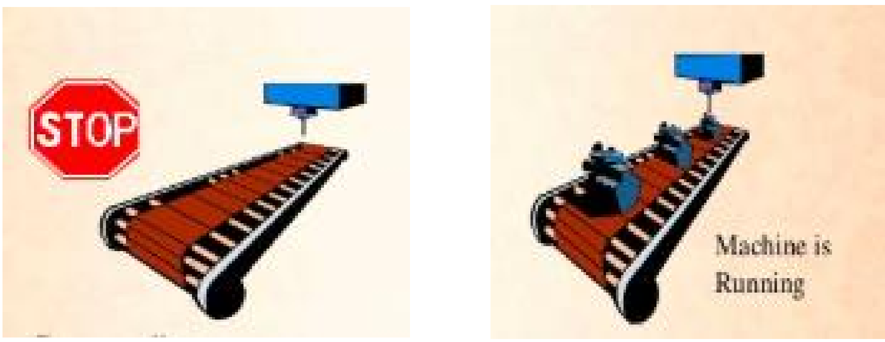


Figure 29 Machine is stopped versus machine is running

External setup time

It refers to the time during which the exchanging operation can be performed even without stopping the machine. Common operations in this category include getting the instructions for the next job, extracting the raw materials needed for the next job from the material warehouse, taking the required molds from the mold warehouse, returning the molds from the previous work to the mold warehouse, and arranging lift the equipment to the right place, arrange the required personnel to the right position, and switch the tailing work.

Adjustment time

After the mold replacement is completed, the time to stop the machine to ensure the quality accuracy and handle the failure is called the adjustment time. It includes machine commissioning, mold adjustments, and the time to trial production of all parts prior to the production of the first qualifying product.

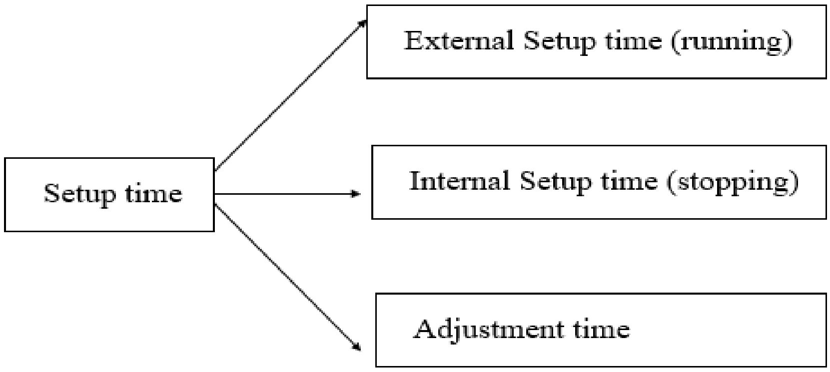


Figure 30 Composition of setup time

4.1.1 Relationship between setup time and product time

The main criterion for measuring the pros and cons of setup is the setup time. In the manufacturing enterprise, there are often many sets of molds that are matched with one piece of equipment. In their normal work, it is inevitable to change the mold frequently, especially in enterprises with many varieties and small batches [21-22].

The traditional concept of mass production is to maximize the production volume and reduce the number of changeovers. Because under the same setup time, the production batch size is larger, and the setup time allocated to the unit product is shorter, that is, the production time per unit product is shorter.

However, in enterprises with multiple varieties and small batches, it is necessary to continuously change between different products, which leads to an increase in the number of changeovers and a long setup time. As a result, it would increase in the number of working hours per unit product and the cost. To reduce the working hours per unit product, an enterprise would increase the production volume of the product, which leads to an increase in the inventory product or the work-in-process product.

What's more, it would also increase the inventory cost, thereby causing an increase in the unit cost of the product.

Under the conditions of the number of times of changeover and other conditions, only implementing SMED to shorten the setup time will reduce the production cost per product. Figure 33 illustrates the relationship between production batch and unit product man-hours under different mold change time conditions (assuming that the processing time per unit product is 1min). In the case of small batch production of 100 products, compared the setup time 480 min to the setup time 1min, the production time per unit product is about 5.7 times (5.8 min/1. 01min)

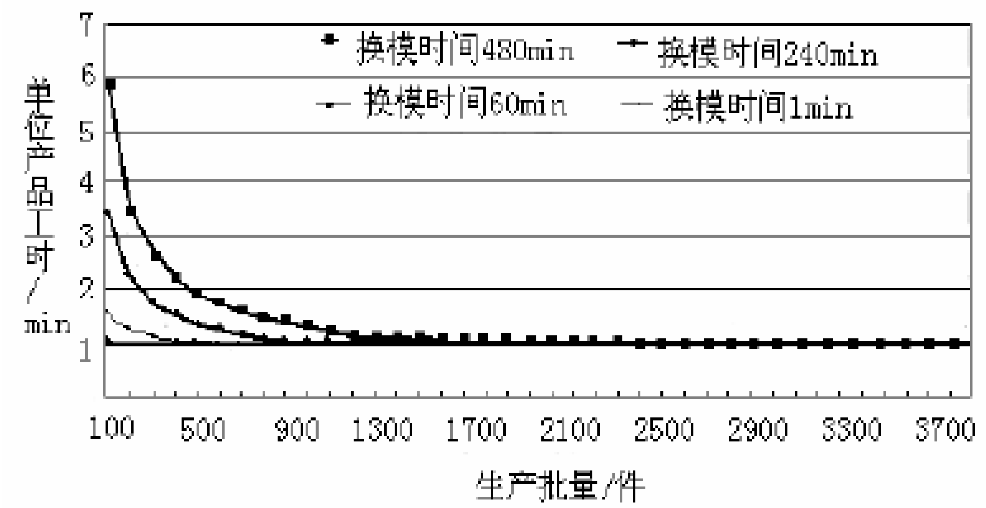


Figure 31 The relationship between batch sizes and product time

4.2 Steps of SMED

Phase 1: Describe the setup process map

Record the status of the exchange preparation process, including the setup time, who usually completes the job, the number of people, the tools, the parts, and the special events that occur during the change of the line [23-25].

Set the improvement goal of the exchange preparation process, including the target value of the setup time and the time to be improved. Although these are the target set before the setup, the target would be proposed after recording the entire exchange process and analyzing the exchange process. As a result, it would usually be better than the set target.

Phase 2: Differentiate setup action

As mentioned earlier, the setup time refers to the time from the completion of the current product to the production of the next qualified product, including the external setup time, the internal setup time and the adjustment time. Before taking various measures to improve the setup process, you should firstly master and record all the contents of the operation, investigate the time spent on the details of each operation, and then specify which operations must stop the machine and which operations do not need to stop the machine. Then, the setup operation is decomposed to internal setup operation, external setup operation, and adjustment job [26-28].

To separate internal from external, Shingo recommended using three different tools:

- Function and performance checks is the tool which would show the availability and the condition of all tools needed for a setup process.
- Check list is that we need to make checklists of all machine parts and the steps required in an operation. This list contains names, specifications, pressures, temperature, dimensions and numerical numbers for all machine sizing types.
- Prepare tools and components ahead of time prior starting setup tasks. Improving transportation systems and other parts in a production process should be done. There are certainly parts that will be moved from storage to production machine. At the same time, there are other parts returned to the storage after lot of product has been completed. This condition will cause operators more frequent to transport when the machine operates. As a result, it is necessary to improve the transportation system more efficiently.

Phase 3: Conversion the internal and external actions

Transfer some internal setup operation that cannot affect production to the external setup operation, and further shorten the setup time up to 30%-50%, which is common to all enterprises, such as preparation inspection before production, using functional fixtures and fast fasteners, tool standardization, advance preheat the mold and so on. In addition, internal production preparation can be transferred to external preparation processes, such as production commissioning, production review, which will directly affect the length of product commissioning time. SMED aims to eliminate adjustment time, not just reduce, strive for a one-time adjustment success.

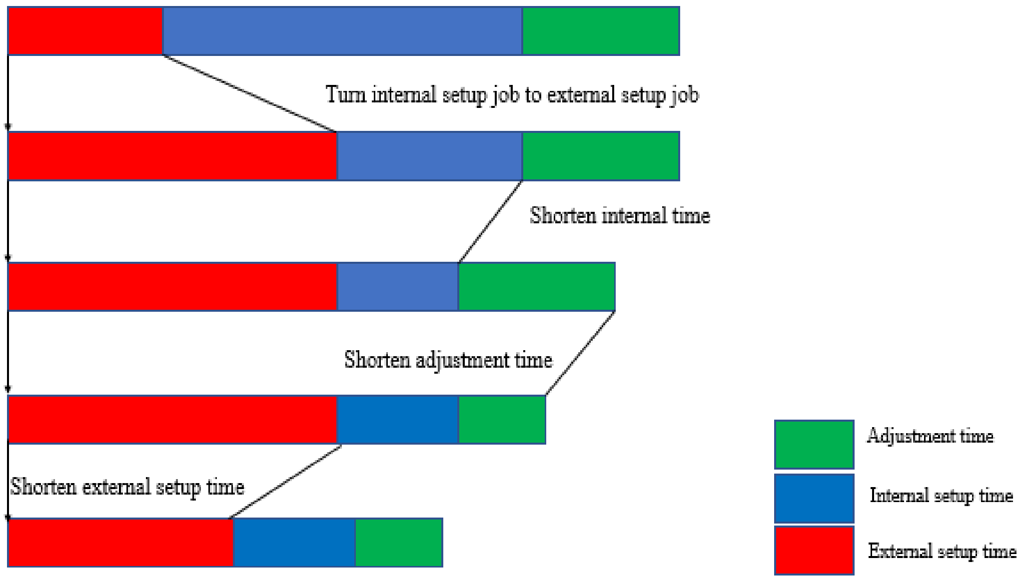


Figure 32 Conversion the internal and external actions

Phase 4: Reduce internal exchange actions

Once the setup operation is clearly defined, different measures can be taken for different operations, and improvement activities of the exchange can be started to shorten the time for implementing SMED. There are some methods to improve internal setup operations as bellowed.

1. Firstly, standardize the conversion operation, analyze the setup time and process, formulate reasonable standardization operation of setup and standardized operation instructions for mold installation operation. Then organize employees to train exchange standard operation to reduce mold setup time.
2. Simplify and standardize loading and unloading clamps and tool operations. It is

better to use quick clamping devices as much as possible and bolts as little as possible so as to reduce mold loading time.

3. Implement parallel operations that two or more collaborative setup operations.
4. Eliminate the waste of unnecessary actions during the product conversion process and strengthen the training of the improved operators.
5. Add a polyurethane elastic lifting device when design the mold. It would bring the effect that the mold can be taken out of the storage stopper before entering the internal setup operation.
6. Use a universal fixing device that facilitates joint between mold and fixing part.
7. Improve bonding mode so that the mold can be easily disassembled and installed.

Phase 5: Reduce external exchange actions

After shortening the internal changeover time, you should also find ways to reduce the external setup time. We can improve the external operation by some different methods, such as: storing the tool next to the machine, setting the hand tool table next to the machine, and putting the ruler store on the side of the machine, preparing a checklist for tool replacement preparation, providing detailed tool replacement process record sheets, etc.

In order to completely eliminate the waste, it is necessary to completely implement 5S, namely sort, set in order, shine, standardize and sustain.

1. Formulate operating standards, specify the sequence of operations, switch the tools, appliances, and places where they are placed;
2. Concentrate on the required fixtures, tools, molds, screws, etc. during the process, separate the required and unnecessary, work to reduce the handling times and time, and don’t treat the unnecessary.
3. Placement must be clearly marked so that anyone can see at a glance.
4. Used tools, utensils, molds, etc. must be cleaned and returned to prescribed place.
5. All the workers must develop this habit and be able to persevere.

Table 2 Key point to shorten the setup time.

<table>
<tr><td colspan="3">Key points to shorten the setup time</td></tr>
<tr><td rowspan="8">External setup</td><td>No searching</td><td>tools (kinds/ number)</td></tr>
<tr><td>No moving</td><td>place</td></tr>
<tr><td>No mixing</td><td>place order</td></tr>
<tr><td></td><td>neaten</td></tr>
<tr><td rowspan="4">preparation of ancillary equipment</td><td>fixture inspection</td></tr>
<tr><td>measure instrument</td></tr>
<tr><td>preheat mold</td></tr>
<tr><td>complete installation</td></tr>
<tr><td rowspan="13">Internal setup</td><td rowspan="2">workface</td><td>unified order method</td></tr>
<tr><td>job sharing</td></tr>
<tr><td rowspan="3">basic work thoroughly</td><td>job effectiveness</td></tr>
<tr><td>parallel operation</td></tr>
<tr><td>simplify the job</td></tr>
<tr><td rowspan="3">exclude redo</td><td>personnel</td></tr>
<tr><td>easy installation</td></tr>
<tr><td>complete installation</td></tr>
<tr><td>mold</td><td>fasten method</td></tr>
<tr><td rowspan="2">fixture</td><td>reduce fastening equipment</td></tr>
<tr><td>use special tooling</td></tr>
<tr><td rowspan="2">measuring device</td><td>mold/ tooling fixture common</td></tr>
<tr><td>interchangeability</td></tr>
</table>

Phase 6: Standardization of die change operations

Although the principle of the SMED method seems to be simple, the detailed implementation process includes quantification of the improvement target and operation procedure, and implementation of the improvement scheme, which have a very important influence on the result. Therefore, the SMED method should not be implemented solely, but should be combined with other management or process improvement tools.

It is recommended to use the SMED method in conjunction with the Standard Operation Procedure (SOP). When the optimization of the exchange process has been implemented in a step-by-step manner, the optimization work should be detailed, quantified and standardized to form a formal document, at the same time, all operators should be trained to make them more practical and skillful.

Phase 7: Keep improvement

The improvement of lean production is a gradual improvement, a subtle change. And it will be a great success after a long period of time. Through the improvement, the setup time of the production process is greatly shortened, and the production efficiency is improved. But any improvement is just a small step in the improvement process. Only continuous improvement can make the company continue to find problems and solve problems successfully.

Continuous improvement has several characteristics, namely, planning, organization, system and fullness. This is a major difference between continuous proactive improvement and sporadic passive improvement. It is also an important reason why many companies have improved but failed to achieve a leap in performance. It can be said that keeping continuous improvement is an accumulation of steps and even thousands of miles of behavior, as a result, it is unrealistic to expect that through several management reform movements, it will be possible to achieve the great improvement and spend little time to achieve the goal.

The steps of continuous improvement can be explained by the scientific working procedure of the PDCA cycle. The PDCA cycle was first proposed by Dr. Hugh Hart of Bell Labs in the United States. Later, it was promoted and applied in Japan by Dr. Dai Ming, which proved the scientificity and effectiveness of the PDCA cycle and was called the improvement cycle. And the PDCA cycle divided the work process into the following four different stages.

The first phase is called the planning phase. The main content of this stage is to understand the current production process status through on-the-spot investigation and communication with front-line workers. At the same time, we need to find out the shortcomings, identify the links that need improvement, formulate improvement plans and establish improvement goals.

The second phase is the implementation phase, also known as the do phase. This stage is the content specified in the implementation plan stage. For example, according to the relevant theory of '5W1H', the process of eliminating, combining, rearranging, simplifying, formulating the relevant documents and taking the corresponding measures are carried out. This phase should also include staff training prior to the implementation of the program.

The third stage is the inspection phase also known as check phase. This phase is mainly to check whether the implementation is in line with the expected results of the plan during or after the execution of the plan.

The fourth stage is the processing stage, also known as the action stage. Mainly based on the results of the inspections, it is needed to take corresponding measures to summarize the gains and losses in the improvement process, and timely adjust the unreasonable measures to make the improvement move toward the set goals.

The PDCA cycle is a continuous cycle process that is further improved every time. Continuous improvement would finally reach a high level. There is a strong logic between the steps of the PDCA cycle. The key to the four phases is the summary phase. The summary phase plays the role of the commitment and ensures the PDCA.

The PDCA cycle is a small ring with a small ring. The small ring guarantees a large ring. As it continually circulates, it rises continuously and spirals upward. The enterprise is advancing constantly discovering problems and solving problems. Implementing lean manufacturing and improving the setup process, a small successful result does not represent an improvement in success, or it may be the result of a coincidence. Only learn lessons from the process of each setup process, step by step, can go further on the road of lean production.

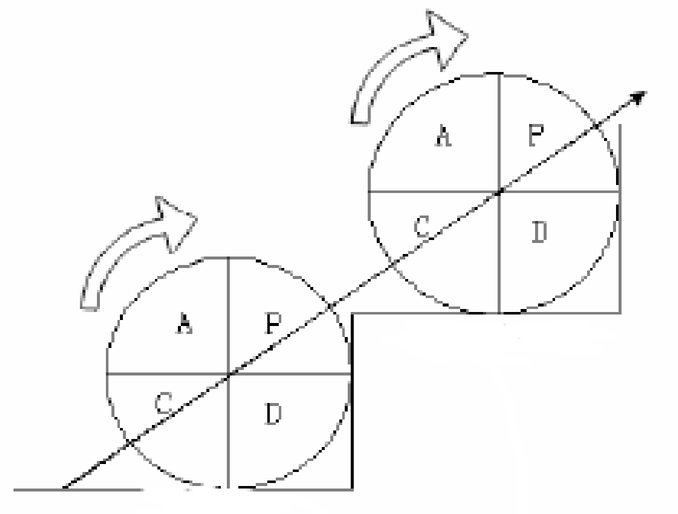


Figure 33 Procedure of PDCA cycle

5 Case Study

Firstly, we can have a better understanding of setup time by some simple setup processes in order to be sure to be competent on such processes. And such examples can be illustrated in detail in order to demonstrate the application of SMED and the shortening of the maintenance time.

5.1 SMED applied in our daily life

5.1.1 SMED applied in health care

If we are changing over an operating room in the hospital, there are many certain things that we can have prepared outside of the machine, such as all of the instruments for the next procedures. These can be done externally. When we talk about cleaning the operating room to prepare it for the next patient, those are all done internal to the operating room.

Suppose that we think about the common mindset within manufacturing, if a machine is down or a resource such as an operating room is not being utilized, then we are wasting resources.

Changeover content can be divided as followed.

- Preparation 30% (internal element)
- Checking and settings 5% (internal element)
- Setting up & adjusting instruments 15% (waste)
- Removing and mounting materials and equipment 50% (external element)

In this case, the internal element means that an element that can only be completed inside the operation room, while the operation room is not in use or stopped. External element means that an element that could be completed while the operation room is still in use. And the element means the changeover task.

5.1.2 SMED applied in F1 Pit Stop

If we consider the setup process in F1, then the setup time is the time between the car enter the maintenance area and the car leave the maintenance area. And it saved a lot of time after applying SMED.

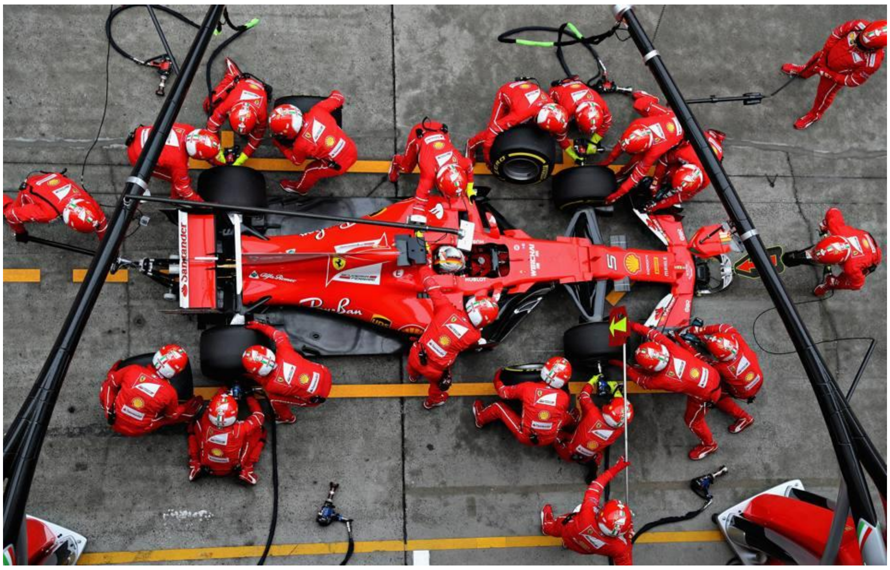


Figure 34 F1 pit stop

In this case, the procedures in setup process are illustrated as followed. Firstly, the technician waited at the expected arrival position of the tire before the car entered the station, trying to shorten the moving distance between the air gun and the racing bolt. And the spare tire was also waiting at the nearest position to ensure that the new tire could be assembled in the shortest time. The actual working time is shortened to the time of removing the bolt and the time of tightening the bolt. Then for the air gun, and the structural requirement is to shorten the occlusion time of the air gun and the nut as much as possible.

5.1.3 SMED applied in changing bulb

When we found the bulb in the room is broken, we need to change it. The setup time in this example is from taking away the broken bulb to installing a new bulb. The setup process in detail are as followed.

1. shut down the electronic sources
2. take the prepared chair and new bulb
3. stand in the chair and take away the broken one to another partner, at the same time, take the new one from partner
4. install the new one
5. ask the partner to turn on the power and check if the new one is working or not
6. at the same time, sort out the chair and broken one

5.2 SMED applied in Stamping Workshop

5.2.1 Introduction of the situation in stamping workshop

In the stamping workshop, the setup time of the traditional large-scale manual production line (T-shaped workbench) accounts for 7% to 10% of the total production time. The medium-sized single-workbench (T-shaped) production line setup time accounts for 5% ~7%. The proportion of various types of time in a medium-sized stamping shop production line is shown in Figure 37.

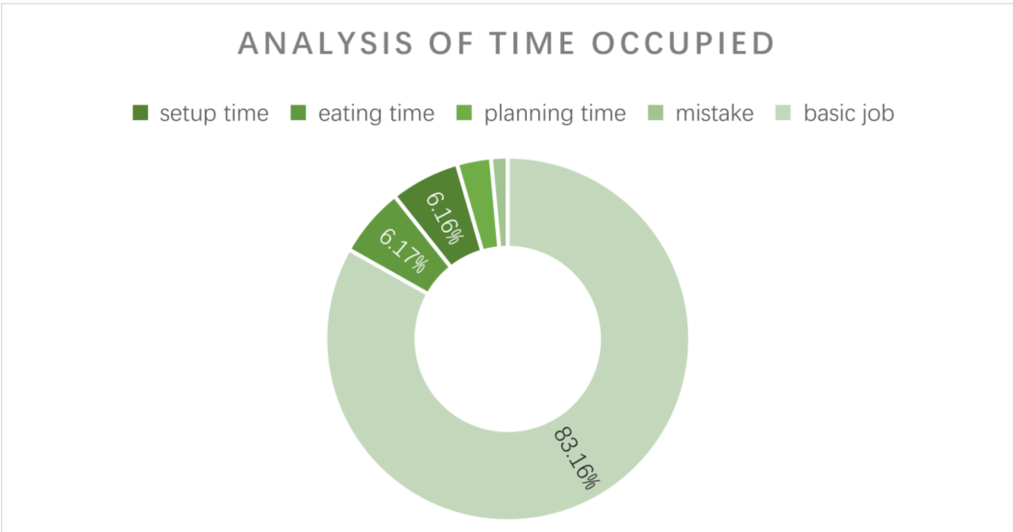


Figure 35 Analysis of time occupied

It can be seen from Figure 37 that the setup time accounts for a large proportion in the whole system time. According to the data, the setup time of the large T-shaped workbench production line is reduced by 1% in the whole system time, and the overall production efficiency can be increased by 4%~ 5%. The setup time of the medium-sized production line is reduced by 1% for the entire system time, and the overall production efficiency can be increased by 3%. Therefore, shortening the setup time is one of the most important factors to improve the overall efficiency.

5.2.2 How to use the SMED

1. Switch the thinking style

(1) Organizing all current work processes, selecting representative molds, and recording the whole process by video recording are necessary. By splitting and counting the above-mentioned mold setup time, the total operation time of the single-sequence die-changing is up to 20 minutes. And the subsequent statistical change time is about 16-20 minutes. The entire setup time is much too long, and the related reasons are as followed.

- unreasonable operation combination
- unclear internal and external operations
- unfavorable parallel operation
- unchanging mold change steps
- inadequate external resource preparation

If the whole setup time is too long, the consistency of production cannot be guaranteed. What's more, the production efficiency is very low which has a great influence on the enterprises. Therefore, research on the improvement of production efficiency is imperative.

(2) The company need to form a group to observe and discuss the whole process, and distinguish between internal work, external work and parallel work.

- Internal setup operation refers to operations that can only be performed after the equipment stops running.

- External setup operation refers to the work done outside the machine during the operation of the equipment.
- Parallel work refers to the simultaneous work of two or more types of jobs. It can be internal or external, and the setup time can be reduced by parallel operations.

2. Optimization of setup operation

We had better to reduce the internal setup time, at the same time, transform the internal operation into external operation as much as possible which also is the core of the SMED method.

Since the internal operation must be stopped, the length of the internal operation time determines the length of the entire setup time. Therefore, to shorten the entire setup adjustment time, the most important thing is to minimize the internal operation, and at the same time simplify the external operation, and must complete all external operation during the operation of the equipment. In this way, it is possible to quickly complete the equipment change and adjustment in a very short time after the equipment is shut down.

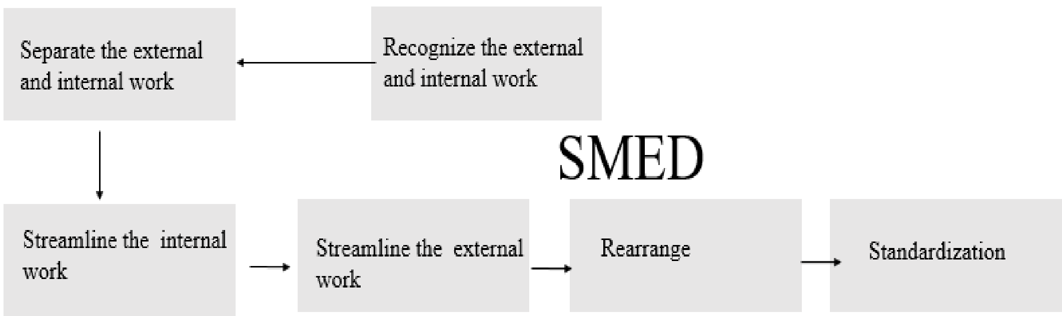


Figure 36 Steps of SMED in stamping workshop

Phase 1 Recognize and separate the external and internal work

Through the above two procedures, we can have a preliminary understanding by decomposing and combing the entire setup production process. And after the splitting steps and the intense discussion, the operation contents in detail can be illustrated in the following table 3.

Table 3 Procedure of setup process

number	procedure	internal operation	External operation	average time (s)
1	new mold preparation		✔	116
2	new mold lifting		✔	64
3	sheet preparation		✔	86
4	bolt removal	✔		4
5	split mold	✔		73
6	hanging on the car	✔		68
7	driving the car	✔		9
8	hang away the old mold	✔		52
9	hang on the new mold	✔		48
10	driving in	✔		7
11	removing the car	✔		3
12	scraping the waste		✔	21
13	covering		✔	18
14	coarse adjustments	✔		89
15	fine adjustments	✔		49
16	looking for a wrench		✔	5
17	bolt installing	✔		3
18	fine adjustments	✔		15
19	opening the waste cover	✔		4
20	fixed waste cover	✔		3
21	looking for scissor		✔	5
22	opening packaging		✔	4
23	test run	✔		3
24	production first	✔		12
total				761

We can find that about 16/24 actions are internal operations which would be the most of time during setup process. 8/24 actions are external operations which can be done before the machine is stopping. Among this, the internal operation is about 58% of the total operation while the external operation is about 42%. In other ways, the external operations can be done before the machine is off which can reduce the setup time effectively and greatly.

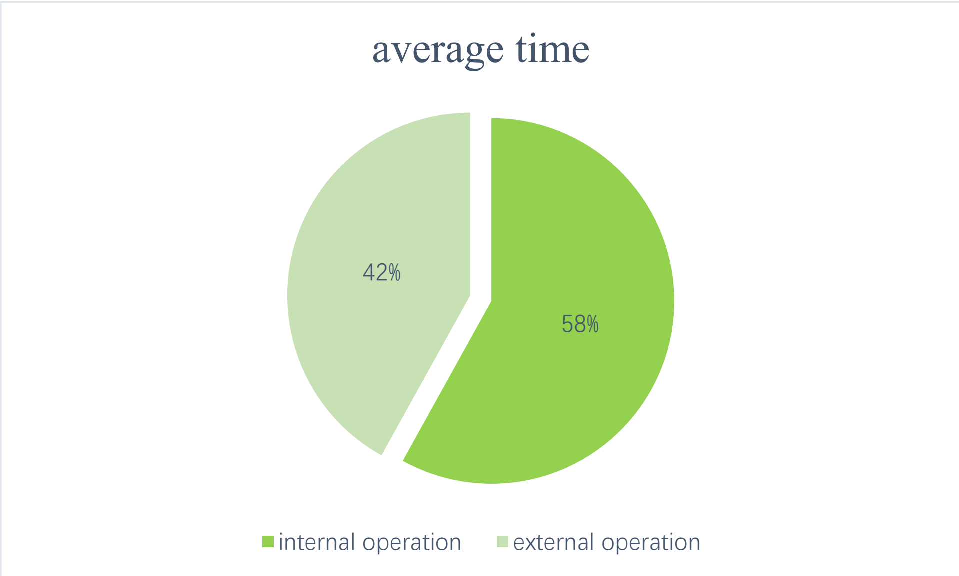


Figure 37 Average internal operation time versus external operation time

Phase 2 Streamline the internal work

When we streamline the internal operation, we need to ask two questions as followed.

- whether all the internal operations must be completed in the machine or it can be changed to external work through improvement.
- whether the internal operations and external operations can be operated in parallel which can reduce downtime.

Table 4 Procedures about internal operation

number	procedure	internal operation
4	bolt removal	✔
5	split mold	✔
6	hanging on the car	✔

7	driving the car	✔
8	hang away the old mold	✔
9	hang on the new mold	✔
10	driving in	✔
11	removing the car	✔
14	coarse adjustments	✔
15	fine adjustments	✔
17	bolt installing	✔
18	fine adjustments	✔
19	opening the waste cover	✔
20	fixed waste cover	✔
23	test run	✔
24	production first	✔

From the table 4, we can provide some specific methods in order to reduce the internal setup time. And the methods are as followed.

1. Action 4, 17:
   - the bolts can be removed or installed by multiple people to reduce the setup time and working time. Before the improvement, this work is in charge of one person which will need much time to finish the job. As a result, we changed the single-employee job to a double-joint cooperation which can not only reduce the labor intensity, but also reduce the number of movements, greatly improve work efficiency and reduce operations time.
2. Action 14:
   - coarse adjustments can be done together with the action 11.
3. Action 19,20:
   - waste cover and the fixed scrap cover can be operated simultaneously with the fine adjustment. In fact, it is also an improvement to convert the above two kinds of operations from internal work to external work.

Phase 3 Streamline the external work

Table 5 Procedures about external operation

number	procedure	External operation
1	new mold preparation	✔
2	new mold lifting	✔
3	sheet preparation	✔
12	scraping the waste	✔
13	covering	✔
16	looking for a wrench	✔
21	looking for scissor	✔
22	opening packaging	✔

1. Action 21, 22
   - Looking for scissors and opening package, it can be synchronized with other operations when it is down. In order to reduce the time of internal and external work, the step of looking for scissors can be considered in the first work station which is equipped with scissors so that they can be taken directly. And we can put these tools in an ordered place to reduce the looking time.
2. Look for waste points. In the actual operation process, there are a lot of waiting and pause between the operations due to the matching work, the cross work and the synchronous work, and the various unreasonable combinations. We must also find unreasonable steps, unreasonable combination of operations, erroneous operations, pauses and waiting to improve the efficiency and reduce the waste time. The various ways to improve the operation are summarized as followed.

   a) Substitute and merge moving actions

   - Use spring, chute, compressed air, conveyor belt instead of movements.
   - Replace movement of other parts of body with the movement of hand or foot.
   - Use mechanized or automation devices instead of movements of human body.
   - Try to combine moving actions with other actions.

- Move together with other actions as far as possible.
- Minimize the movement of the moving operation.

b) Reduce the number of movements

- Concentrate on items and reduce the number of shipments.
- Use transportation to help increase traffic per shipment.
- Carry both hands at the same time.
- Integrate the functionality of multiple parts into one part.

c) Replace the moving action of the large-time value with the moving action of the small-time value

- Use movements with short moving distances whenever possible.
- Adjust the height of the workbench and work chair.
- Use horizontal and backward movement to replace up and down movement.
- Use horizontal movements instead of front and rear movements.
- Try to replace complex body movements with simple body movements.
- Design the movements to have a rhythm
- Use springs, chutes, compressed air, conveyor belts, etc. to reduce movement and shorten time.

d) Substitution and merger actions

- Use magnet attraction, vacuum suction, etc. to assist in grabbing items.
- Design tools to capture more than two items.
- Combine the captured action with other actions as much as possible to achieve simultaneous action.

e) Simplify the catching action

- Use a guide rail.
- Use a sliding or rolling conveyor.
- Apply tool parts in different colors to increase the resolution of the grip.
- Optimize the shape of the item to make it easy to grab.

f) Simplified placement

- Use equipment with brakes.
- Use the guide rails to reduce the accuracy of the placement position.
- Fix the items in term of stacking position.
- Combine placement and movement into combined action
- Automatically pull the tool back into the storage area with the aid of a spring.
- When one hand is placed, the other hand assists.
- Determine the appropriate part combination tolerances.
- Design the fit of the part as circular as possible.

3. In the actual setup process, through observation and analysis, it is found that the length of the setup time is different due to the different proficiency of the employees in the internal work. How to standardize the internal operation and let everyone master it is another important link to shorten the setup time.

Phase 4 Rearrange and standardization

To this end, after analysis and discussion about the internal and external operation, we have re-optimized and organized the above steps:

1. Combine the original part of the operation
2. Make the Standard Operation Process (SOP) file to make clear and detailed
3. Train multi-skilled workers and strengthen training skills for employees
    a) Training is the transfer of knowledge from the skill giver to the skill learner through images, sounds, body language, etc. In this process, we mainly filmed the standardized operation process into video in advance through the video teaching method, and then let the students concentrate on watching the video, and then practice the practice, and the operation in the process has problems and timely guidance.
4. Regularly conduct skills appraisal for employees
    a) Assessment is very important and a test of learning outcomes. What's more, it is generally divided into two parts that are written score and practical score.

We first develop the assessment criteria, according to the following formula:

Total score = written test score * 50% + actual exercise score * 50%

b) The assessment requires a total score of 90 or more, and the individual scores are above 85. The high assessment requirements are the guarantee for the standardized training results, and the guarantee of the actual operation consistency after the standardization operation.

Table 6 Standard Operation Process

Standard Operation Process			
setup	**operation procedure**	**Operation essentials**	**PS**
Disassemble the mold	Comprehensive inspection, light rubbing, maintenance mold	Two safety bolts placed diagonally	
	Putting on storage limiter	Pay attention to whether the chain that stores the limiter is placed at the guiding mechanism.	
	Saving the slider to the elastic limiter deformation position	Special care must be taken when using the inching, and the height of the mold should be adjusted when the upper mold is close to the rigid stopper.	
	Removing all bolts	Do a good job of division of labor, the machine chief must confirm that all bolts are removed	PO
	Inching moves the slider to the bottom dead center	First adjust the height of the mold and confirm that the bolts are all removed.	
Die change plate pull out	Turning the pad guide pulley to open and fix		
	Operating the die change button to remove the mold	The pad must be jacked up to be able to move out	
	Mold hanging away	Pay attention to the top hole of the pad and the T-shaped groove for foreign objects such as patches.	

	Hanging mold to be produced and placing it in the middle	To check, gently wipe the bottom surface of the mold and the bottom surface of the mold	
Die change plate advancement	Opening and securing the pad guide pulley		
	Operating the die change button to advance the mold	To jack up the guide	
Mold installation	Rough height	When the height of the mold is adjusted, it must be carried out at the top and bottom of the slider.	
	First open the main motor	Observe the main motor ammeter	
	Inching moves the slider to the elastic storage limiter deformation position	Be careful with inching	
	Locking upper die screw	Check confirmation	PO
	Inching moves the slider to the top dead center		
	Removing the mold storage stopper	Pay attention to whether the chain that stores the limiter is placed at the guiding mechanism.	
	Comprehensive inspection lightly cleans the mold	Two safety bolts placed diagonally	
	Debug balancer	Slider stops at 90° or 270°	
Production preparation	Fine adjustment height		
	Running with inching stroke		
	Locking lower mold bolt		PO
	Inching slider to top dead center, ready for production		

5.2.3 Evaluation of the SMED

5.2.3.1 Direct effect

Since launch of the project, the passion in the company for improvement has been very high and at the same time, some results have been achieved. With the greatly increase in employee proficiency and the division of internal and external operations, the proportion of switching in the second half of the system has gradually decreased, while General stroke per hour (GSPH) is generally on the rise. Of course, the improvement of comprehensive efficiency depends not only on the shortening of the setup time, but also on the improvement of the workshop in terms of refueling, standardization of operation, improvement of bottlenecks and rational configuration of personnel.

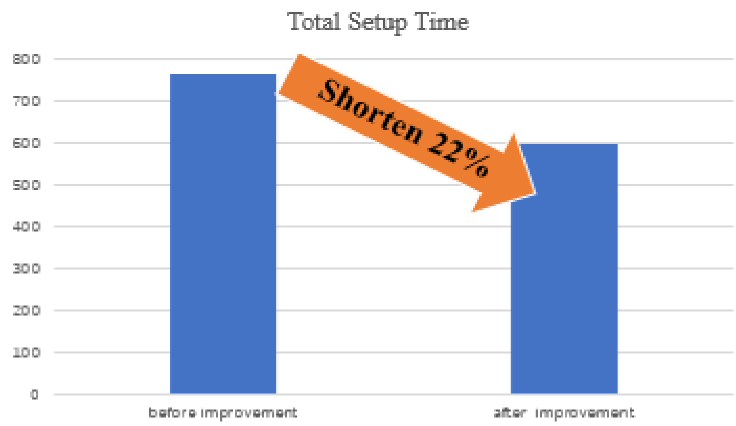


Figure 38 Comparation of total setup time before and after using SMED

From the figure 40, we can find that the total setup time has been reduced to 22% after applying the SMED. And after the latest single-sequence die-change test, the current setup time can reach less than 10min, the overall GSPH is increased by 8% to 10%, and the efficiency is improved by about 5%. There is still a lot of improvement work yet to be started. We believe that after continuous optimization and improvement, the single-sequence changeover time will be further shortened. What we can do are that improvement of the bottleneck position, the balance of the beat, the shortening of the refueling and the problem of the mold problem, and the improvement of the self-protection of the TMP equipment. We strive to improve the overall efficiency of the stamping from all angles.

Table 7 Procedures after using SMED

number	procedure	internal operation	external operation	average time (s)
1	new mold preparation		✓	92
2	new mold lifting		✓	53
3	sheet preparation		✓	60
4	bolt removal	✓		2
5	split mold	✓		58
6	hanging on the car	✓		52
7	driving the car	✓		9
8	hang away the old mold	✓		40
9	hang on the new mold	✓		42
10	driving in	✓		7
11	removing the car coarse adjustment	✓		72
12	scraping the waste		✓	17
13	covering		✓	14
14	fine adjustments	✓		41
15	looking for a wrench		✓	5
16	bolt installing	✓		1
17	fine adjustments opening the waste cover fixed waste cover	✓		15
18	looking for scissor opening packaging		✓	2
19	test run	✓		3
20	production first	✓		12
total				597

5.2.3.2 Indirect effect

The stamping workshop took the lead in the company to carry out SMED activities. Through continuous trial and effort, in the end, the difficulties were overcome, the time for setup operation was greatly shortened, the overall efficiency of the equipment, the productivity of production and the production capacity were improved. On-site 5S, ECRP principles and other aspects are further strengthened in this case and employees' awareness of standardization operations is also obviously strengthened. For example, when employees are engaged in non-replacement operations, they can actively consult with engineering management personnel or indicate on-site operation instructions (SOP) which has deficiencies or doubts

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Appendix

Single Minute Exchange of Die Table

the product before setup: ______ Operator: ______ Team member: ______

the product after setup: ______ Recorder: ______ Date: ______

Number	Job description	Accumulated time	Movement distance	Internal	External	Hands-on time	Walking time	Waiting time	Adjustment time	Improved seggustions
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
Total										