POLITECNICO DI TORINO

Department of Mechanical & Aerospace Engineering
Master's Degree Program in Automotive Engineering

Master’s Degree Thesis

Analysis of Single Minute Exchange Die in manufacturing processes

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December 2020

Acknowledgments

Throughout the writing of this thesis, I have received a great deal of support and assistance. Many people helped me along the way in my academic career. I want to take a moment to thank them.

Firstly, I would first like to thank my supervisor, Professor Paolo Chiabert, whose expertise was invaluable in the research questions and methodology. Your insightful feedback and guidance provide me to sharpen my thinking and brought my work to a higher level.

Furthermore, I would like to thank references authors, Some of them are legends, like Taiichi Ohno, Shigeo Shingo, Steven Boris. I appreciate their valuable expertise experiences that help a lot to give me ideas for my thesis writing.

Besides, I owe more than thanks to my families which include my mother Yang Congrong and uncle Yang Wenyin for providing me with unfailing support and continuous encouragement throughout my years of study and their wise counsel and sympathetic ear. This accomplishment would not have been possible without them.

Last but not least important, I could not have completed this thesis without the support of all my friends who provided stimulating discussions as well as happy distractions to rest my mind outside of my research.

Abstract

The decreasing setup time is necessary for profitability in many industries in the modern era of rapidly increasing variety and smaller batch sizes. More than 20% of the expected output period is spent on improvements in a few industries with many changeovers at moments. SMED (Single Minute Exchange of Die) is one of several Lean manufacturing (also called Toyota Production system) methods used to reduce production time in the manufacturing system, it has been developed in Japan by Shigeo Shingo with a particular emphasis on the identification of internal and external activities. It implies the changeover of internal activities in as many numbers as possible into external activities, as well as the reduction of internal activities. SMED methods play an important part in optimizing the capacities of the equipment over the long term, low volume, and high-speed product production, it's generally to improve OEE (Over Equipment Effectiveness).

Certainly, by applying the SMED methods, the setup and changeover times can be significantly reduced. To minimize 7 wastes of lean manufacturing, potential savings in time have been achieved. In several kinds of industries, the SMED method is well-proven. The purpose is to reduce transitions between hours and minutes. However, products remain to undergo enormous challenges in rapid production and quality assurance through the small batch and multi-variety production process. This paper will introduce Six Sigma and Lean Manufacturing while enhancing manufacturing performance and quality assurance, engage in research on integrating the SMED methodology in Lean manufacturing links to Six Sigma and establish sequential analysis.

Furthermore, this paper also challenges the concepts of ergonomics are discussed within the SMED methods. The setup time was reduced and the risk of MSD (Musculoskeletal Disorder) was also reduced through the SMED methods and increasing ergonomic conditions.

Key Words: SMED methods, Lean manufacturing, Six sigma, Ergonomics

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1. Introduction

If an automotive industry moves from one car model to another, it must change all facilities and processes to satisfy the required parts. The changeover time means that the module, system, or machine must be prepared for the change from the last good part from the last batch to the first good part of the new batch, it is a waste of workforce during setup time. This reduction of setup time is minimized by large production. The ideas of Taiichi Ohno are what was achieved from the customer's point of view to avoid any procedures that did not favor the customer. Lean concepts describe the product value as the customer perceives it and then align it with customer pulls and aim to enhance it constantly by reducing waste through the classification of Value Added activity (VA) and Non-Value Added activity (NVA). [1]There are various types of bottlenecks to the output flow in lean production, the Seven Wastes of NVA can be seen in Figure 1.1, also called Muda that Taiichi Ohno began to search. These challenges contribute to additional processing or time expended, but they do not add value to the consumer. He brings cutting changeover time tasks to Shigeo Shingo who has successfully developed Single Minute Exchange Die (SMED) methods which is one of the lean manufacturing techniques. It is also referred to as a quick changeover methodology. Mostly every manufacturing process can be evaluated using SMED technology, and every maintenance activity or operating sequence can also be verified. SMED method is seeking waste in terms of additional steps, incorrect steps, simpler steps with the use of screws, preparation steps, mixed steps, and brainstorming to find better steps.[2]

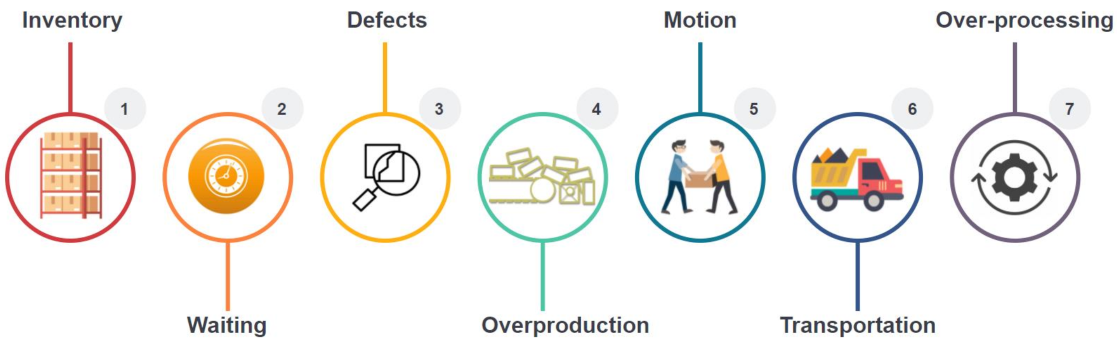


Figure 1.1: 7 wastes of Lean Manufacturing

1.1 Overview of Lean manufacturing

Lean Manufacturing is an industrial methodology that aims to optimize operational efficiency by generating value for its ultimate customer. It enhances operational efficiency by concentrating on the rapid and continuous flow by the value stream of materials and supplies. To use it, it is important to identify and eliminate various types of production waste. Waste can include any operation, process, or step that does not add customer value. Waste management is one of the key requisites for developing a profitable company. This framework is part of Lean methodology and leads to improved profitability for businesses. Taiichi Ohno identified three main bottlenecks that may have a negative impact on the company's production line as shown in Figure 1.2: Muda (Waste), Muri (Unreasonableness), and Mura (Inequality).

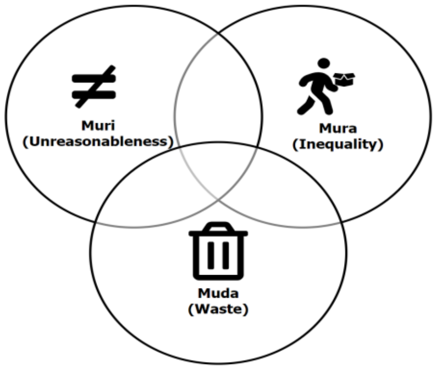


Figure 1.2: Muda, Muri, Mura

1.2 Evolution of Lean manufacturing techniques

Earlier researchers have investigated Value Stream Mapping (VSM) as the principal element of the lean manufacturing method to visualize the process and the flows of information required for the product to be transformed into the finished product. The Push and Pull system, as mentioned, relies on consumer demands, while the Push system relies on a predefined plan. Cellular manufacturing determines the grouping of the facility so that the product is generated smoothly with the minimum processing time, waiting time, and shipping. Further, rapidly changing line flow is enhanced by the line balancing concept, KANBAN is a material flow control system which supplies the appropriate quantity of parts at the proper time. One-piece flow guarantees a just-in-time(JIT) manufacturing system to follow a straightforward routine without delay, backflow, or scrap, minimizing the Takt time and reducing the risk of machine failure and structural failure. Single Minute Die Exchange (SMED) systematically decreases the changeover time by transforming potential internal setting time into external time and simplifying and simplifying the rest of the activity. The Lean manufacturing methodology is applied successfully through alignment and simultaneous application of Lean techniques and the proper procedure. [1]

Figure 1.3 has been proposed an evolution roadmap of lean techniques comprehensive implementation that provides a coherent theory for the implementation of the Lean Manufacturing System.

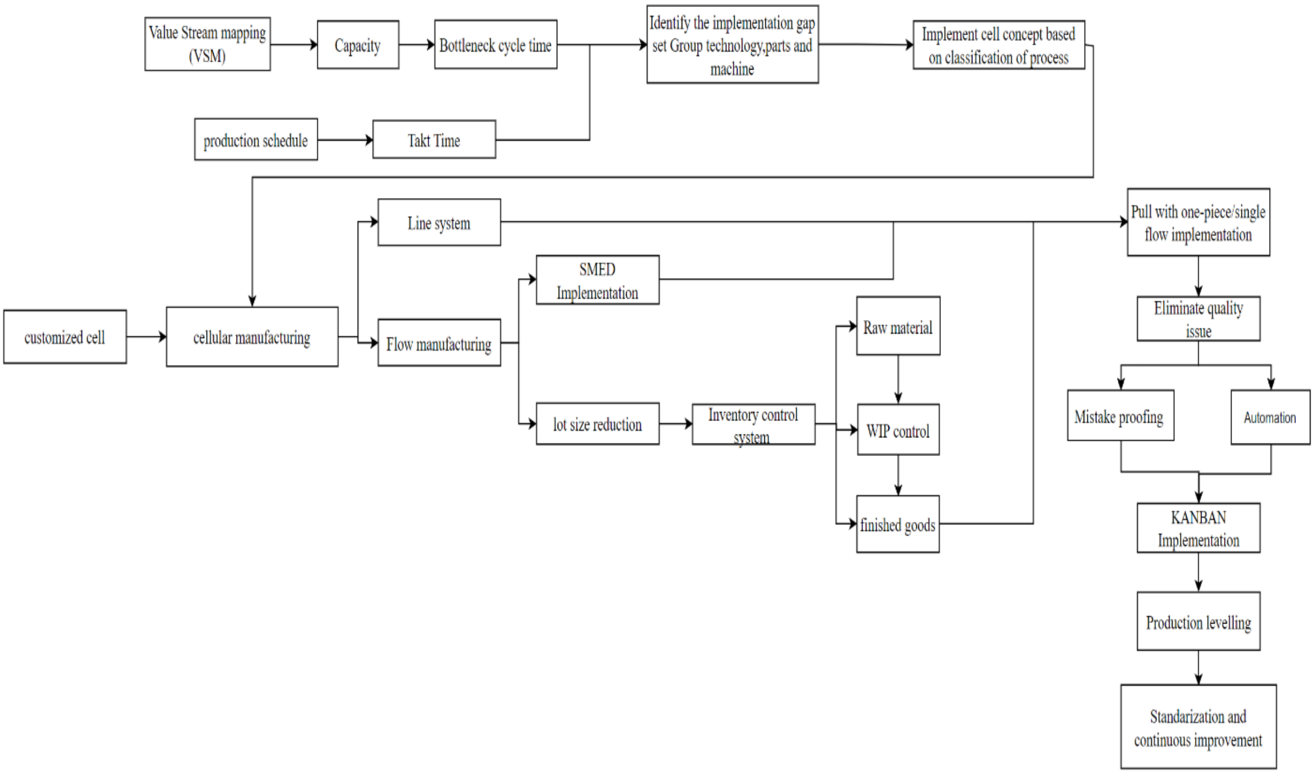


Figure 1.3: Evolution roadmap of Lean manufacturing techniques

1.3 Brief introduction of Lean techniques and their implementation

1.3.1 Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a vital tool to identify logistics and information flow within the Lean manufacturing early studies development approach.VSM may be used to identify and find causes of waste as a starting point for supervisors, engineers, workers, production planners, suppliers, and customers. By visually representing the logistics and the knowledge flow in the production phase, VSM achieves the above objectives. The VSM could be seen in Figure 1.4, it starts working from the moment the raw material is obtained. It goes through all production stages and processes before the finished product leaves the facility. The main purpose of VSM analysis is to immediately expose the existing 7 wastes problem and eliminate wastes. The value available in the VSM decides to adopt the lean tool faster and validating more effectively and can stimulate the company to get the desired results during the implementation phase. VSM specifically defines inventory, setup time, leading time, waiting, and process flow from which the bottleneck cycle time can be sorted against the Takt time.[1]

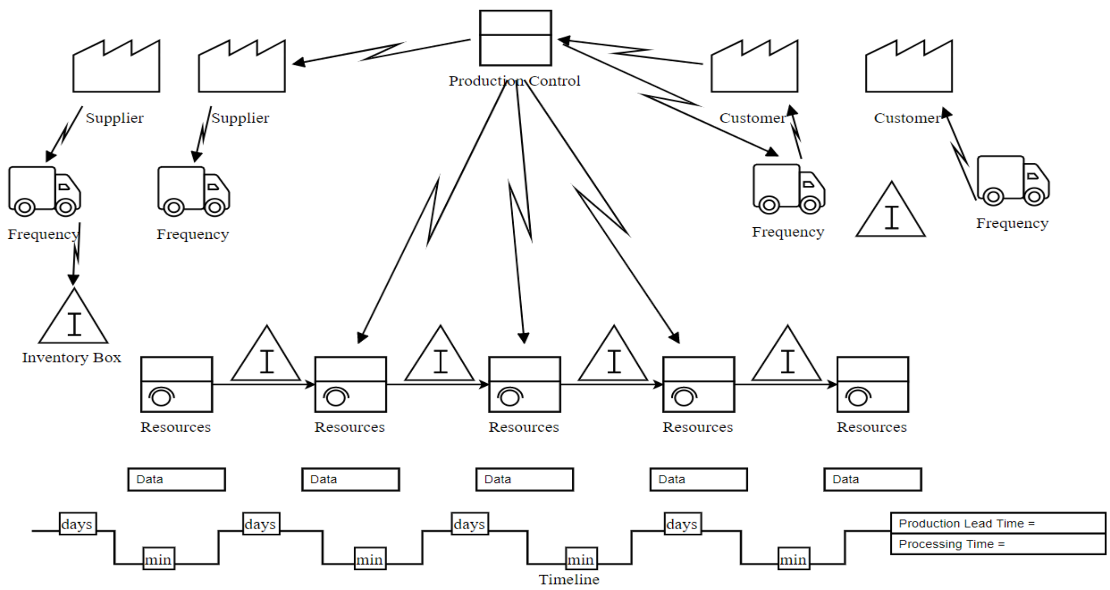


Figure 1.4: Value Stream Mapping

The following formulas below give an overview of process data that may be of use for Value Stream Mapping(VSM).

$$Lead\ Time = Cycle\ Time + Transportation\ Time \tag{1.1}$$

$$Process\ efficiency = \frac{\sum Process\ Time}{\sum Lead\ Time} \tag{1.2}$$

$$Total\ Lead\ Time = Value\ Added\ Time + Non\ Value\ Added\ Time \tag{1.3}$$

1.3.2 Takt time

Takt term referring to the pace of output of a part or item for the customer's request. It can be determined within formula (1), T_a represents the net available time which is the amount of time available for work to be achieved. if the demand (D) increases, the Takt time (T) decreases, the Takt time (T) increases and the output intervening increases or decreases. If the customer demand (D) decreases, the Takt time (T_t)decreases.[1]

$$D = \frac{T_a}{T_t} \tag{1.4}$$

1.3.3 Single Minute Exchange Die (SMED)

SMED has been developed by Shigeo Shingo to reduce bottlenecks in the Toyota production system caused by tooling machines. The machinery was not completely capable when SMED technology was built, so the expectations were not published. SMED is currently one of several lean manufacturing methods for wastes reduction, providing a quick and effective way of reducing changing times. It systematically eliminates change over time, by converting potential internal time to external time and simplifying and optimizing the recovery method. The SMED analysis in Figure 1.5 has seven basic phases. It is intended to ensure that consistently the SMED activity tends to minimize the changeover time.[2]

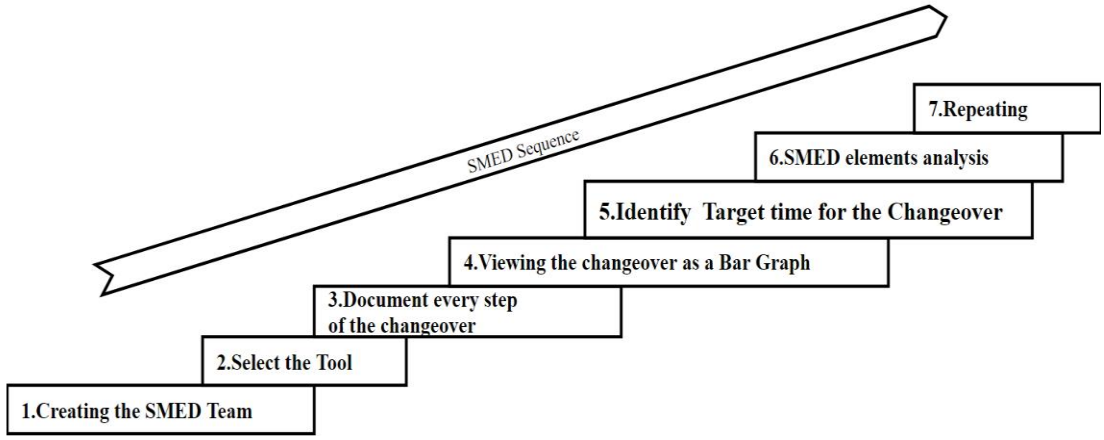


Figure 1.5: SMED Sequence

✧ Phase 1: Creating the SMED team

Before the team is formed, the appropriate team will be trained to use the SMED technique or implement the SMED method during the preparation. It includes technicians, engineers, and managers. At least some of the team members need to know the tool and be able to make the move, and other suggested team members, such as equipment suppliers who may be aware of more up-to-date methods and components and instructors/facilitators who are aware of the procedure and can sustain an analysis momentum, are safe to make more complicated modifications required.

✧ Phase 2: Select the Tool

The tool selected should be checked and should benefit significantly from a revised process. It helps to look for bottleneck route, and be careful to choose a tool for a changeover during the course of the transformation, or even prepare a decent deal in advance for the best transformation at the moment, etc.

✧ Phase 3: Document every step of the changeover

SMED requires that every action be recorded as shown in Figure1.6, each task consists of a series of steps or elements which are necessary to complete. Much like every term consists of some letters, every element consists of several smaller elements also called sub-elements. In real cases, we could use a notebook, observation sheet, photographs, and videos to recording information.

Line	
Machine	
Operators	

Required Setup tools	

Standard setup time

N°	Task / Operation	Actual time		Improvement	Target time		Necessary activities
		Internal	External		Internal	External	
1							
2							
3							

Figure 1.6: SMED record sheet

✧ Phase 4: Viewing the changeover as a bar chart

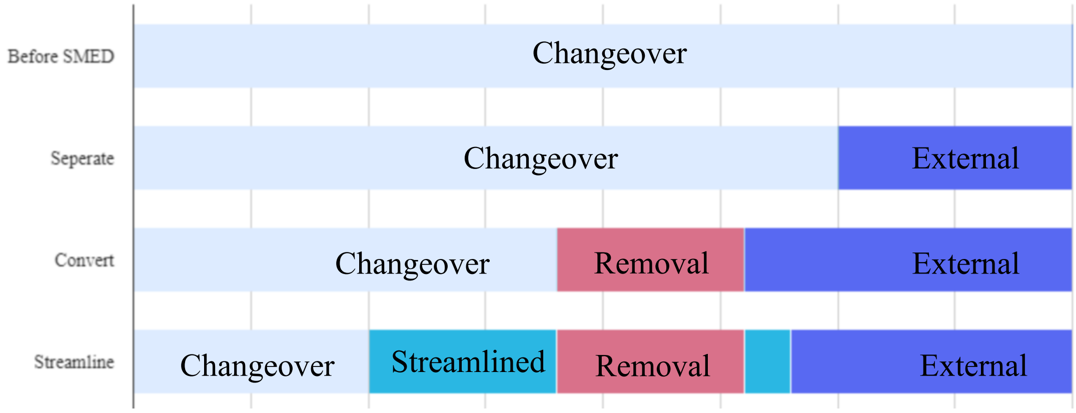


Figure 1.7: SMED system bar chart

✧ Phase 5: Identify Target time for the Changeover

The target time should be team motivation. Supposed the reduction time is at least 50% of initial production time that is reasonable for first-time reduction planning, it could be shown in Figure 1.6.

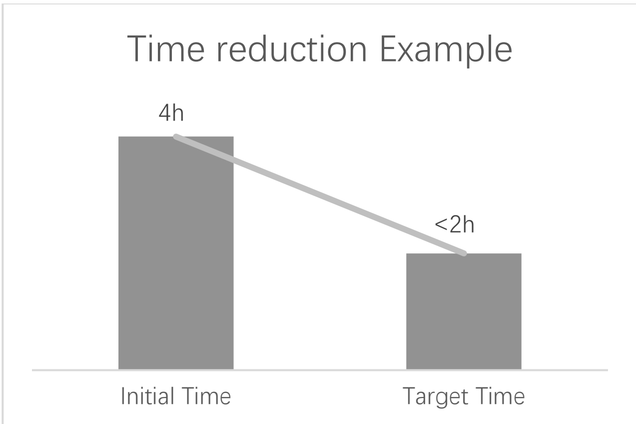


Figure 1.8: Time reduction plan hypothesis

✧ Phase 6: SMED elements analysis

The SMED elements analysis is carried out by the whole team with the facilitator decides on the implementation plan. The elements can be listed in Figure 1.6 chart. When we evaluate the analysis chart components, we take each in sequence to decide if a valid move is a team.

✧ Phase 7: Repeating

The final step is never really accomplished in principle in the SMED analysis. The purpose is that the analysis should repeat itself for an infinite period at fixed intervals of 6 months. However, it is likely in fact that the change priority list will be used to guide the use of SMED teams, particularly in the early days, where changes are made and prioritized in terms of profit. In compliance with the expected benefits, each new technique should be re-evaluated to the list.

1.3.4 5S: Default organization and enhancement

5S is a default organization method that uses a list of five Japanese words: seiri , seiton , seisō , seiketsu , and shitsuke which translated as shown in Figure 1.7.[3]The 5S methodology is normally accepted as a basis for continuous techniques for improvement. It is also a feasible way to present the definitions of waste and efficiency to laborers. It facilitates a clean, efficient ecosystem and encourages workers to develop their way of working. The method will also facilitate the creation of improved layouts, enhanced storage systems, and innovative, best strategies for determining the correct components as 5 S will recognize and eliminate unnecessary items and tools and general uncertainty. 5S allows pollution sources to be detected and removed and increases product quality again by physically cleaning and maintenance of the ecosystem.[2]

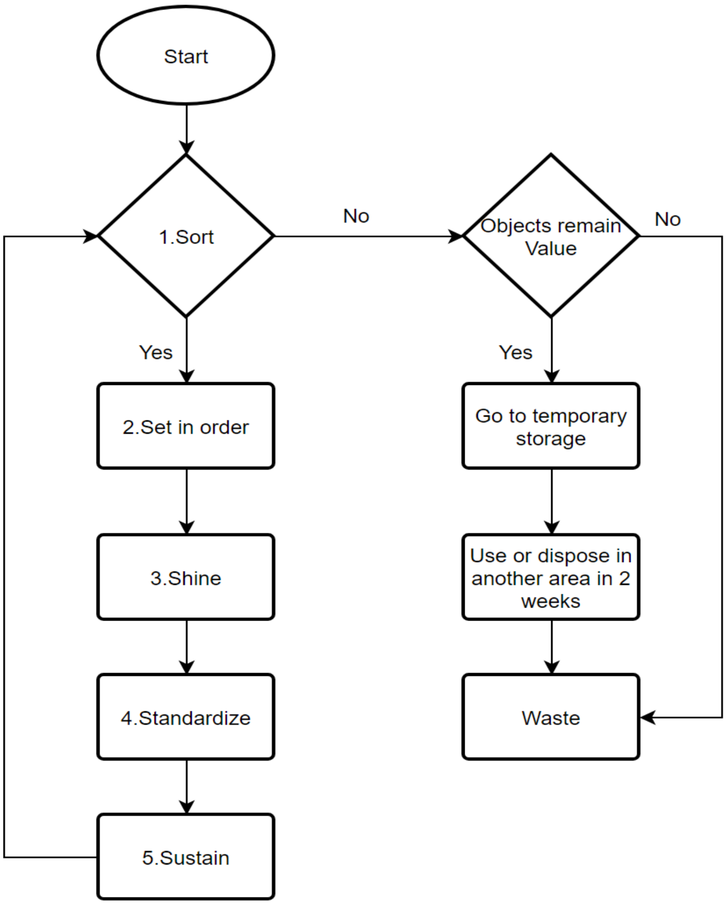


Figure 1.9: 5S implementation procedure

The 5S is an effective strategic tool that can improve environmental hygiene, climate changes, and criteria for health and safety. The 5S sort stage removes unused, unnecessary shop floor materials that eliminate the uncertainty. The elimination of non-productive time increases productivity. The effects of 5S are obvious in a short time after 5s implementation. Employment in the business becomes autonomous.[4]

1.3.5 Small lot size production

The production of small lot size is a significant factor in many Lean Manufacturing strategies. Lot size impacts inventory and scheduling directly. Small lots minimize process variation and streamlined manufacturing. Small lots have the advantage in comparison to large lot production which they are very flexible, it could be seen in Figure 1.8. For a pull method to adopt, in which goods are manufactured according to customer demands, small lots are the practice. It increases efficiency, simplifies scheduling, reduces inventory, and practically eliminates waste especially when products are produced after customer demand, also doesn't require much investment to get started and encourages sustainable improvement.

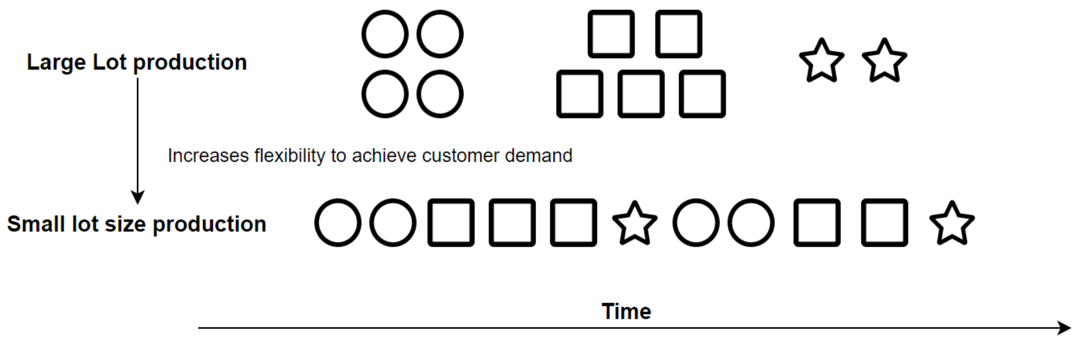
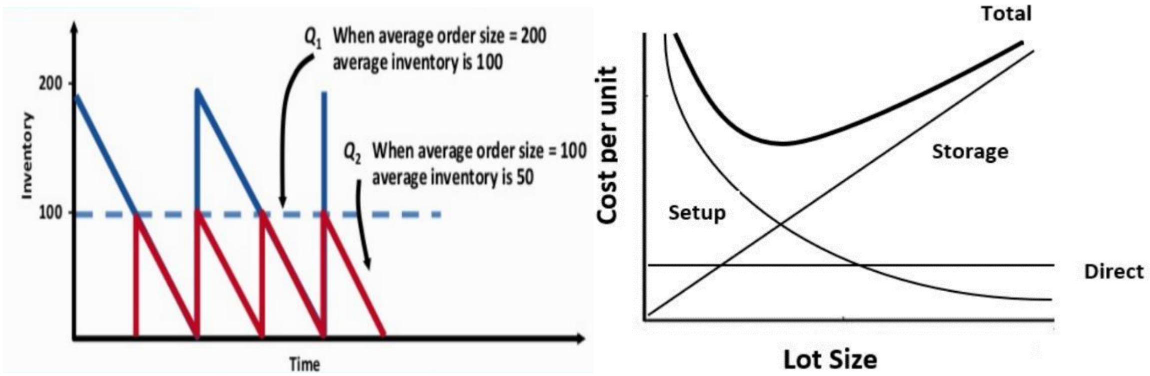


Figure 1.10: Large lot versus Small lot

Figure 1.10 (a) has been shown an EOQ(Economic Order Quantity) model example of lot size reduction, which represents by lowering the order size will let inventory decreases as well as reduces the inventory cost. Figure 1.10 (b) could be seen as the setup cost is higher when it's in small lot size and rapidly decreases with increasing lot size, but the inventory cost per unit proportional to the lot size, the small lot size has economic inventory cost. So the setup reduction (SMED) has somewhat different effects on MTO (Make-To-Order) and MTS(Make-To-Stock) ecosystem as shown in Table 1.1 of their possible situations. Simple setups promote small batches and small batches mean more setups that improve support and the ability of setup. Furthermore, the cost system for the items will become very low. [5]

Table 1.1: MTO and MTS effect on setup reduction

MTS (Make-To-Stock)	MTO (Make-To-Order)
Small lot size optimization	Lower minimum order size
Decrease Total cost	Higher margins
Decrease Inventory	Increase delivery efficient



(a) (b)

Figure 1.11: (a) EOQ model of lot size reduction (b)Cost-Lot size relationships

1.4 Review of Six Sigma and Lean Six Sigma concept

The triple constraints are Time, Cost, and Quality, which are used to show the tensions for a project that needs to balance when meeting its objectives. Lean is a continuous improvement process that is focused on improved customer demand satisfaction that concentrates on waste management and the streamlining of the product or service delivery process. This will decreases the time and cost of the product. Six Sigma is a quantitative methodology that has been launched during its 1986 work at Motorola by the American engineer Bill Smith. [6]It is aimed at enhancing output efficiency through data collection and measurement to reduce mistakes and differences. This increases the quality of the product. Six Sigma involves the production and design of a product which it approaches as shown in Figure 1.12. Lean and six sigma essential combination makes Lean Six Sigma. It is an optimization approach focused on both mathematical process control, quality, and profitability in the case of Six Sigma is not appropriate for solving small problems that do not involve a significant number of variables. Every step of Six Sigma management and every step of lean production are complementary and synergistic. Taking the DMAIC method as an example, the specific process of Lean Six Sigma implementation is shown in Figure 1.13.

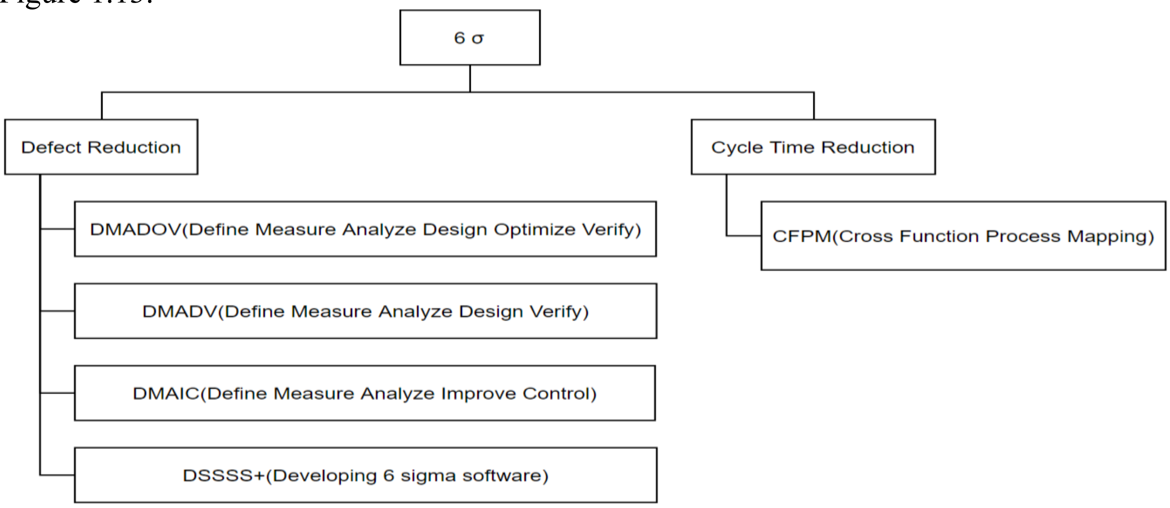


Figure 1.12: 6 sigma approaches structure

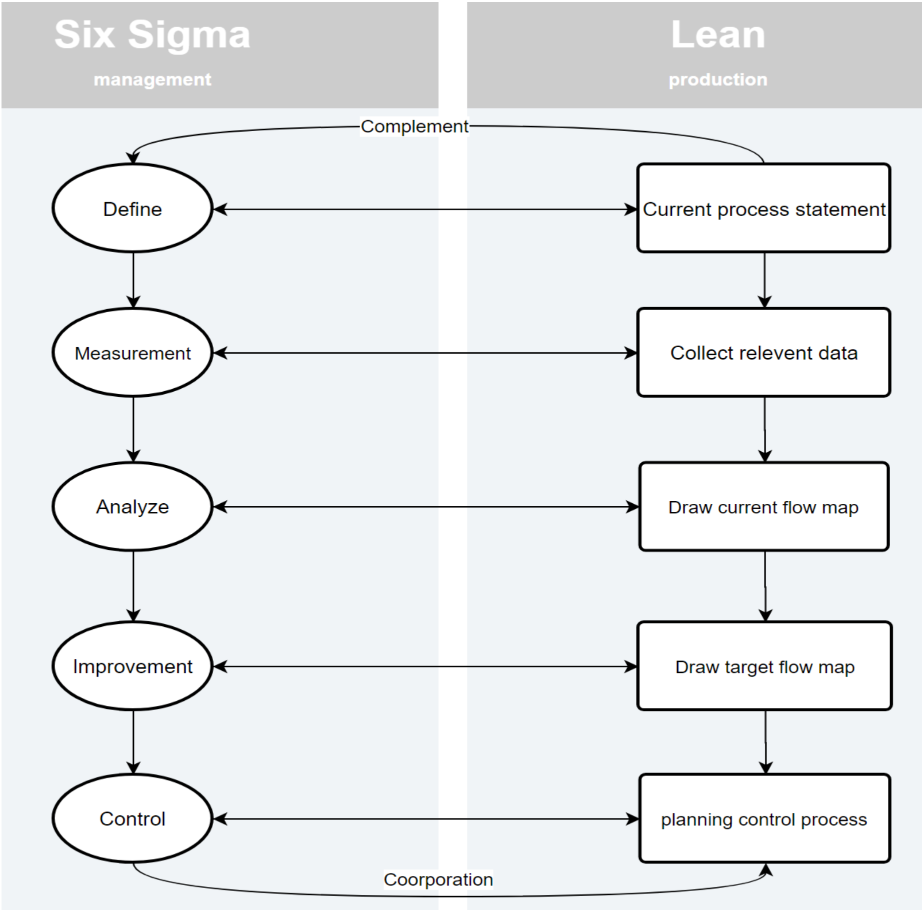


Figure 1.13: Lean and 6 sigma DMAIC combination

2. SMED methodology under the Lean Six Sigma process

2.1 The criteria for SMED implementation

An enterprise has strong relationships with the intensity of customer satisfaction to sustain and develop. As the market develops, every day the customer demands of the company are rising, from initial low prices to the high quality of the objects, and then the customer's goals are fulfilled, with quality and quantities being accomplished on time. Manufacturers must generate innovations more rapidly and better than our alternatives, seek to lead and to generate profit in time to discriminate in market competition. The problems of periodic mold exchange and low utilization of equipment caused by multiple varieties or small lots are essential to solving for saving time. That includes the use of the SMED technique, mold optimization, streamlined mold change procedures, and optimization of mold changeover time internally and externally. To reduce the changeover time and setup time for mold is necessary for companies to have a competitive advantage. Figure 2.1 shows that customer satisfaction is constantly changing and improving, the company competitiveness must be improved accordingly. Therefore, SMED is one of the major reasons for businesses to strengthen their competitive advantage.

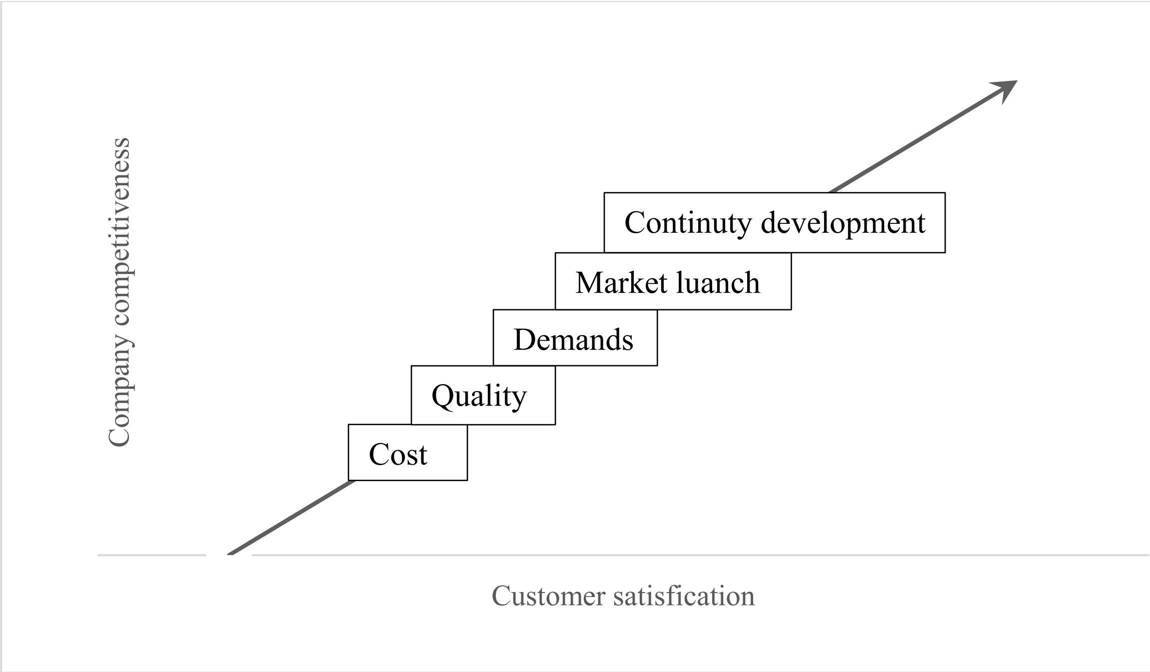


Figure 2.1: SMED techenique implementation criteria

As shown in Figure 2.2(a), the initial production begins with part A, makes a changeover, and then produces part B and makes another changeover. After the second changeover, we again produce part A and repeat the cycle. The inventory of part A increases during the processing of A and declines during all certain times, is also similar for part B. Once part A has finished its production process, we must have adequate pieces to last us for two changeovers, and part B production until we get more part A. After using the SMED technique, it would have been possible to reduce the changeover time by 50%. The changeover now only takes half of the time. Figure 2.2(b) indicates the initial sequence of processing and changeovers at the top and the current sequence with the changeover time decreased by half at the bottom which could free up time. This would free up time equal to one or two of the established changeover times. The SMED technique significantly extra production capacity then we could produce more parts and minimizing cost per unit, also at the same customer demand, the T_a(net available time) is decreasing which implies the Takt time(T) is decreased.

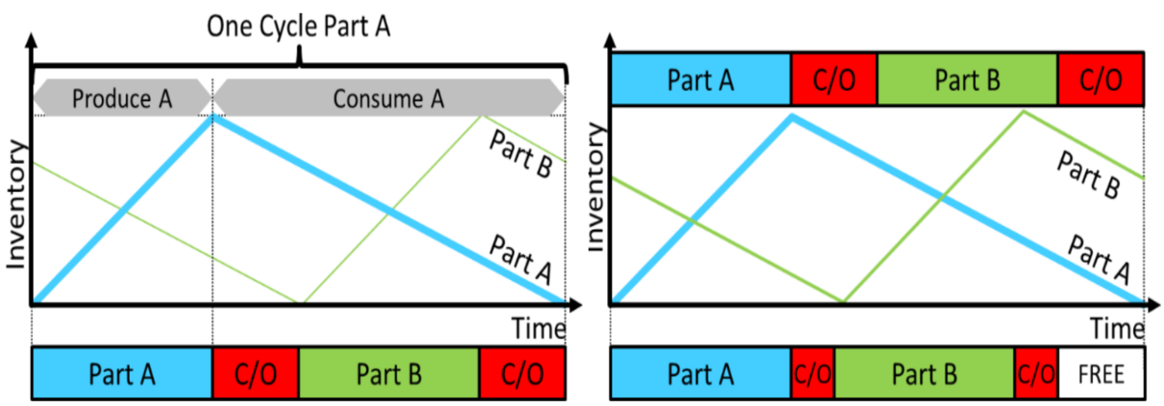


Figure 2.2: (a)Initial production (b) Half Changeover Time after SMED

2.2 Lean Six Sigma methodology

The lean tools tended to require less quantitative analysis than Six Sigma tools, and they were mainly applicable to improvement in operations about constraints in the flow of physical products or work units. Six sigma and lean systems tended to be viewed as separate and distinct improvement methods in the middle-to-late 1990s. Nowadays, many organizations have begun to integrate six sigma and lean along with project management and business reengineering.[7] To successfully integrate Lean Six Sigma, a hybrid of lean manufacturing and Six Sigma tools must be used, for example, value stream mapping as shown in Figure 2.2 is a lean six sigma flow chart by taking the DMAIC method and SMED technique and other lean tools. The lean six sigma structure has 5 stages, as shown in Figure 2.3, with each stage offering a simple and systemic guide to the main cause identification of the problem, thus introducing and executing a reasonable alternative to mitigate the root cause through continual improvement, but this structure is by no means the only method that can be used in the Lean six sigma implementation. [6]The structure employs the data-driven and oriented standard approach of the Six Sigma DMAIC methodology by using lean tools at each stage to identify development opportunities and further evaluate problems.

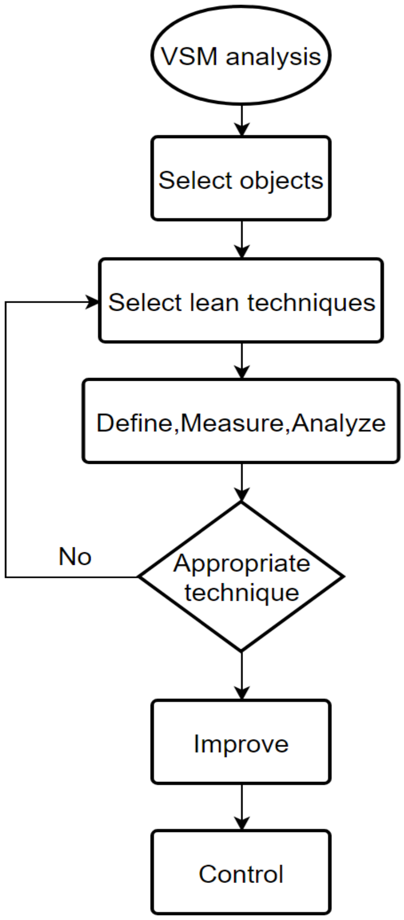


Figure 2.2: Lean six sigma methodology flowchart

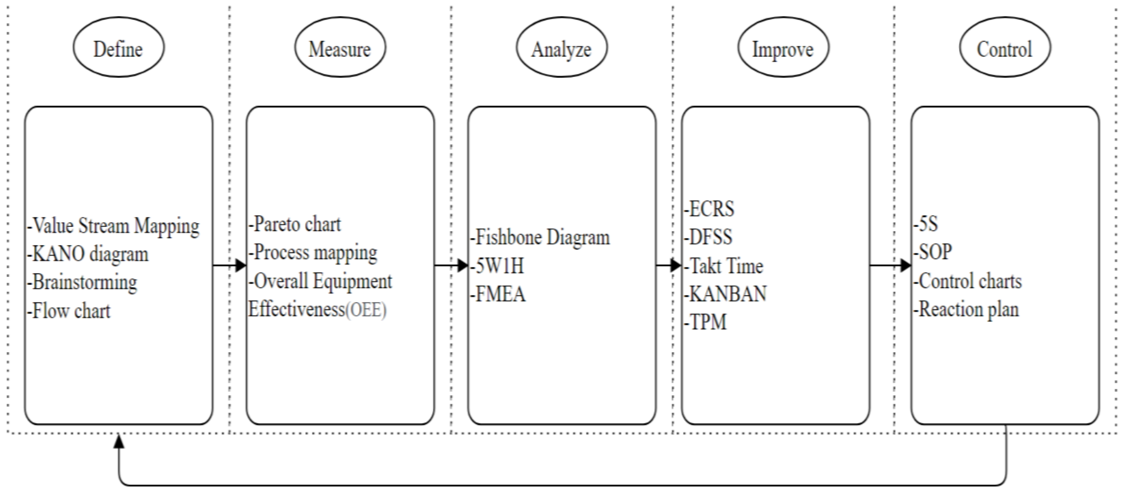


Figure 2.3: Lean six sigma DMAIC tools structure

2.2.1 Define: Identify the issues

Collect data using relevant data to assess the current status, implement Value Stream Mapping (VSM) and KANO diagram and other tools as shown in Figure 2.3 which will help to analyze which phases of the process actually add value to the product and then go through the flowchart systematically to figure out where attention needs to be pulled. This phase defines the system, the voice of the customer and their requirements, and the project goals specifically. [8] In the 1980s Professor Noriaki Kano developed the Kano model as shown in Figure 2.4 is a product development and customer satisfaction theory that categorizes customer preferences into five categories. The KANO model helps to assess the fundamentals and helps lean six sigma teams to emphasize the key factors in the improvement process.

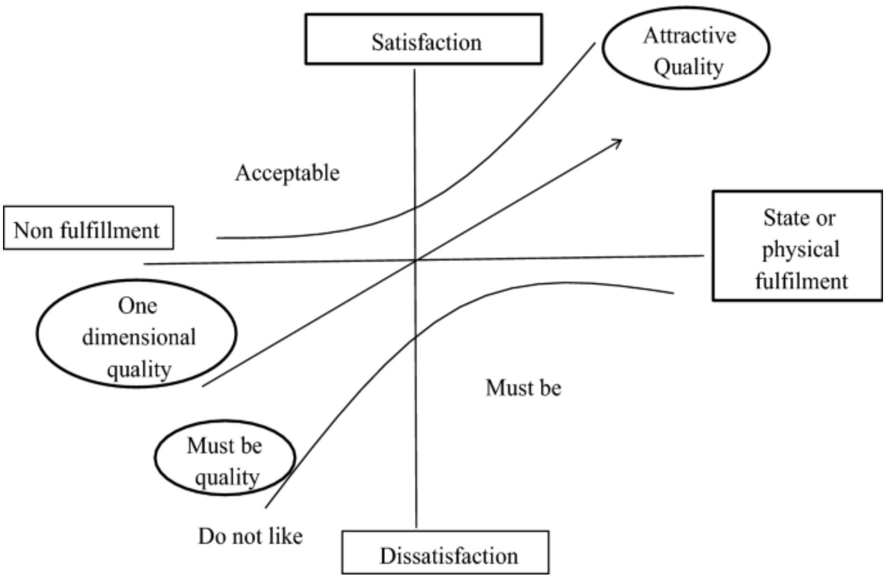


Figure 2.4: KANO diagram

2.2.2 Measure: Evaluation of data analysis and root causes identification

Data obtained at the previous stage should be analyzed using methods such as process mapping, OEE (Overall Equipment Effectiveness), and Pareto chart. Measure phase has key aspects of the current process phase and collect sufficient data and measure the current process capacity.

By using the OEE(Overall Equipment Effectiveness) concepts, as suggested by Nakajima in 1982, integrated into the Lean Six Sigma's DMAIC method to improve process efficiency and effectiveness.[9] By evaluating OEE and the related losses, critical information could be obtained into how the manufacturing process can be systematically improved. OEE is an essential measure for determining losses, benchmarking performance, and improving the efficiency of manufacturing equipment, for example by eliminating waste. It measures the overall efficiency of processes by measuring the three key loss factors: technological Availability(A), Quality rate(Q), and Performance efficiency(P), these factors allow for a better understanding of which kind of losses are affecting the production. The generic calculation formula of OEE is:

$$OEE = A\% \times P\% \times Q\% \tag{2.1}$$

Which technological availability is considering planned and unplanned stops. The 100% technological availability score implies the manufacturing process is kept running during loading time. Table 2.1 shows the sources of the issues for the technological Availability of the process OEE. The issues are contributed by the Planned Downtime components such as the Daily Preventive Maintenance (DPM) and the changeover activity and by the Unplanned Downtime components such as Equipment Related errors and Non-Equipment Related errors.

$$A\% = \frac{Operating\ time}{Loading\ Time} \tag{2.2}$$

$$Operating\ Time = Loading\ Time - (Non - operating\ time)$$

$$Operating\ Time = Loading\ Time - \left(\sum Downtime\ + \sum Stop\ Time\right) \tag{2.3}$$

$$Loading\ Time = Total\ Time - \sum Downtime \tag{2.4}$$

Table 2.1 Possible issues affect technological Availability

Planned Downtime	Unplanned Downtime	
DPM	Equipment	Non-Equipment
Changeover Monthly PM	Machine error Noneffective process Noneffective SPC	Process Tools and fixtures

The performance efficiency is taking into account slow cycles and small stops. The 100% means the process running is as soon as possible. Figure 2.5 shows the sources of the possible issues for the Performance efficiency of the process OEE measurement in the lean six sigma DMAIC method. The issues are accounted to break time, batch size, low nest utilization target, and higher Idle time between Loads.

$$P\% = \frac{Theoretical\ Cycle\ Time \times Produced\ Amount}{Operating\ Time} \tag{2.5}$$

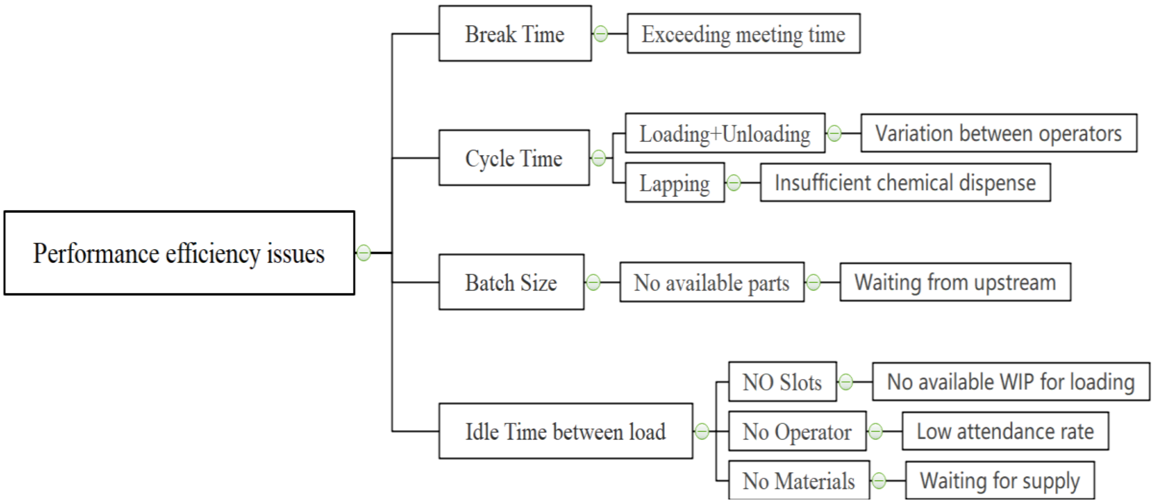


Figure 2.5: Possible issues affect Performance efficiency

The Quality rate is considering defects that occur when products do not meet quality specifications, even though they can be re-produced to correct the failure. The 100% quality rate is the goal of zero defects to produce every time. The following Table 2.2 shows the sources of the issues for the Quality rate of the process OEE measurement. The issues are Too Few Zone, Higher Abort Rate, Passive Lapping and Row aborted.

$$Q\% = \frac{Total\ Produced - Defects}{Total\ Produced} = \frac{Good\ Produced}{Total\ Produced} \tag{2.6}$$

Table 2.2 Possible issues affect the Quality rate

Too few zones	User abort	Passive lapping	Row aborted
Replacement issue	Missed handling	Not good nest	Dead sliders
Stock issue	E-bond issue	Not alignment	
Incomplete workbench			

The Pareto chart is a type of graph that includes both bars and a line graph, where the key elements are expressed by bars in descending order, and the cumulative sum is represented by a line. The map takes its name from the Pareto concept, and the name comes from the well-known Italian economist Vilfredo Pareto. Figure 2.6 shows a CNC machine SMED real setup time of the Pareto chart, the left vertical axis is the frequency of occurrence, but it can alternatively represent cost or another important unit of measure. The right vertical axis is the cumulative percentage of the total number of real setup time in minutes of measure. [10]Because the values are in decreasing order, the cumulative function is a curve. The purpose of the Pareto chart is to emphasize the most important among several factors. It also constitutes the most common causes of defects, the most common form of defect measurement or the most common explanation for customer complaints, and so on in the Six Sigma quality management field.[11]

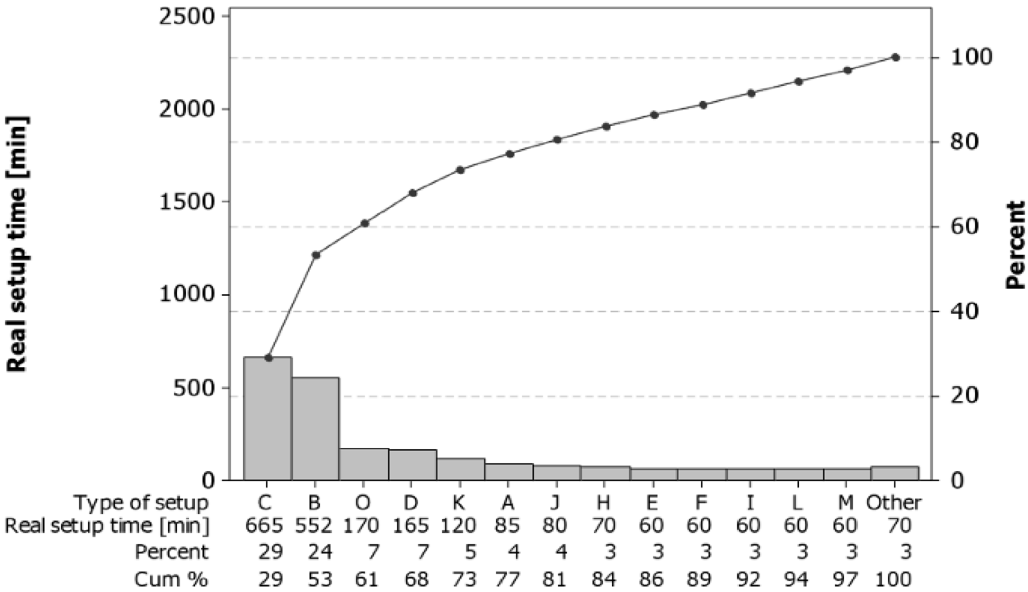


Figure 2.6: Pareto diagram

2.2.3 Analyze: Problem analysis

Analyze phase is most important in the Lean Six Sigma DMAIC method, at this stage identification of the fundamental issue of the defect under investigation is essential. This can be achieved by using tools such as Fishbone (Ishikawa) diagram, 5W1H analysis, and P-FMEA analysis. Analyze data to explore and evaluate relationships of cause and effect. Identify the relationships and continue to ensure that all aspects are taken into account.

The following steps to be followed in the analysis phase of the Lean Six Sigma DMAIC method are[12]:
1. Examine the process closely by performing time analysis and other value-added analysis based on customer requirements and waste removal.
2. Get a plot graph or any quality control tool such as histogram, Pareto charts based on the data collected from the measure phase.
3. Brainstorm potential causes using any root cause analysis tool such as Fishbone diagram, 5W1H analysis, P-FMEA methodology, etc.

4. After finding root issues perform process analysis, comparative analysis to verify whether the root issues are the real causes for the problems or not.
5. Tabulate the impacts of the causes and objectives of the group.

The possibilities of the SMED method example which target is to reduce the setup time to a single minute were deployed in Fishbone (Ishikawa) Diagram as sown in Figure 2.7.

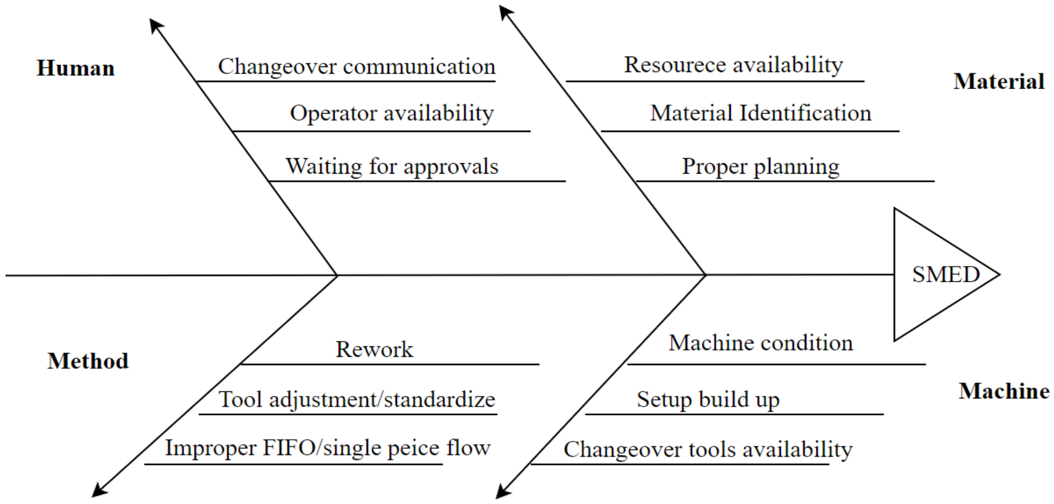


Figure 2.7: SMED method Fishbone diagram

The 5W1H concept as shown in Figure 2.8 of Lean Six Sigma DMAIC methodology can allow businesses to identify all factors of the Six Sigma situation in particular and can thus be applied when evaluating the business process for improvement opportunities. Interactions also enable Six Sigma participants to take systematic, defect-free measures to effectively complete the Six Sigma project on time and every time.

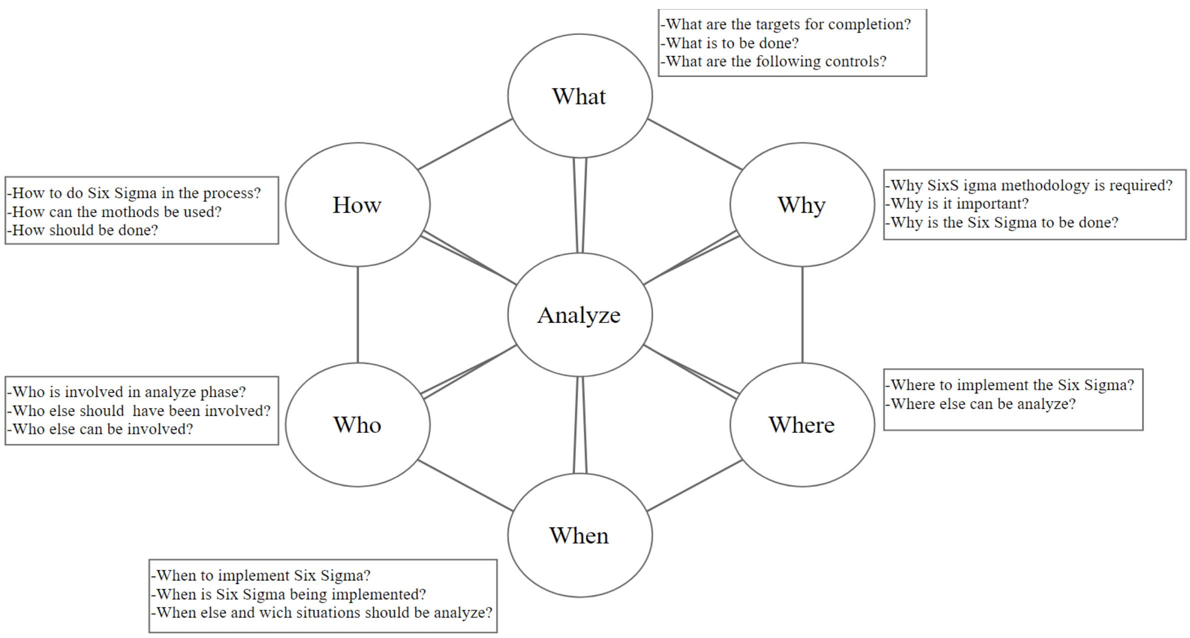


Figure 2.8: DMAIC-Analyze phase 5W1H analysis diagram

FMEA (Failure mode and effects analysis) is used during the analysis phase of the Six Sigma DMAIC cycle. It may help project stakeholders define product features and process activities that are more sensitive to defects and failures. Equipped with the knowledge that FMEA provides, project teams can increase product quality and minimize errors by changing internal processes or developing a new method to fix possible defects. FMEA identifies all the probable failure modes for the product or process. It prioritizes the failure modes for focused attention by using a Risk Priority Number (RPN) scoring model based on three key factors: Severity (S), Occurrence (O), and Detectability (D). It can be created to contain the risk. It is used as a living document and could be a good foundation for building robustness. When improving the failure mode, the models with higher risk and larger impact are prioritized for improvement.

$$RPN = S \times O \times D \tag{2.7}$$

2.2.4 Improve: Current progress optimization

The Improve phase of the Six Sigma DMAIC methodology aims at implementing a feasible solution. This can be achieved by using tools such as ECRS (Eliminate, Combine, Rearrange and Simplify) and DFSS (Design For Six Sigma) to improve or enhance the current system based on data analysis using techniques such as experiment design, error testing, and standard work to create a modern, future state-of-the-art process. Set up the pilot to build up the process functionality. The ECRS concepts in related to the previous Analyze phase tool 5W1H as shown in Figure 2.9. ECRS represents the four key concepts as[12]:

1. E (Eliminate): Eliminate waste found in throughputs, such as processing time, unnecessary movement, and work process.
2. C (Combine): Combine excessive work actions to minimize the number of work moves and the overall processing time.
3. R (Rearrange): Rearrange any successive steps to reduce interference of movement or the number of actions.
4. S (Simplify): Simplify or suggest a better way of operating or create extra equipment, such as support tools or equipment modification to improve operators.

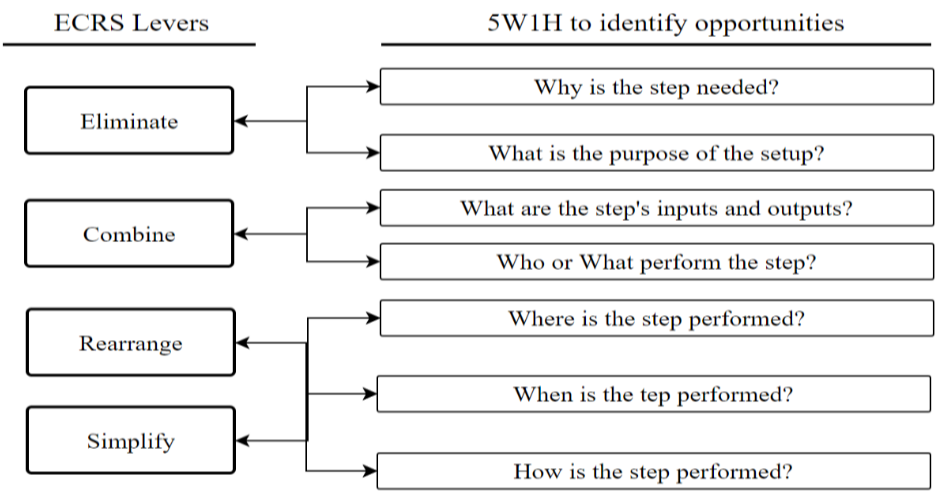


Figure 2.9: 5W1H in relation to ECRS

The DFSS (Design For Six Sigma) methodology also called DMADV (Define, Measure, Analyze, Design, Verify) project methodology which is features five phases[8]:

1. Define: Goals definition design that is consistent with customer demands and the enterprise strategy.
2. Measure: CTQs (Critical To Quality) measurement and identification, measure product capabilities, production process capability, and measure risks.
3. Analyze: Develop and design alternatives analysis.
4. Design: Improve alternatives design, best-suited analysis in the previous stage.
5. Verify: Design, set up pilot runs verification, implement the production process, and hand it over to the process owners.

The DFSS methodology improves the conventional Six-Sigma approach but shares the ultimate aim of reducing defects and of helping a business to the high-quality effort to satisfy consumer demands. In the DMAIC methodology of lean Six Sigma, the DFSS approach is improving with design on the current progress, then verifies whether it is successful.

2.2.5 Control: Integrate improvements to ensure sustainability

The control phase is the final stage within the Lean Six Sigma DMAIC methodology, its possible future procedure to determine that any variations from the objective are resolved before they cause defects. The purpose of the control phase is to ensure that performance improvements made by the project team are sustained over time. Implement monitoring systems such as statistical process control, production boards, visual workstations, and continuously monitoring its progress. The Control activity helps ensure progress improvements are kept on track by following the key performance measures, and this process is repeated until the desired quality consistency is reached. Every successful Control phase activity must be prepared to plan a set of seven attributes that need to be considered after the asset Lean Six Sigma DMAIC improvement phase:

1. Measurements and Specifications: After a cautious analysis of the previous improvement process, the control phase should have been established. This ensures that the finished product or service aligns with the customer's specifications.
2. Input and Output: To maintain the control phase unrestricted, control information that is critical for keeping the whole project on track, the determination of the varying input and output parameters, and the improvement phase at which the control phase reaches.
3. Process Design and Execution: The control phase plan to built around the final progress of Lean Six Sigma, and determining appropriate standards for the current process and setting associated performance criteria is the main step.
4. Frequency of Reporting And Sampling Methodology: Defining a reporting and sampling sequence guarantees an adequate buffer period for appropriate corrective action. The periodic analysis makes tighter monitoring and control better.
5. Recording: Documentation of information at the control phase of the progress is important to allow for better assessment, planning, testing, and implementation. Documentation sheets are used to record and store information for current progress.
6. Corrective Actions: A framework to implement suitable corrective actions is a must-have in the Control phase planning.
7. Progress owner identification and Documentation: Process owners are the persons who are responsible for and possess the requisite authority to make changes to the current process midway through a project.

Use of tools such as Standard Operating Procedures (SOP), 5S as shown in Figure 1.9 the Lean techniques and control charts, etc. By using the 5S methodology that this technique is very useful and beneficial in lean manufacturing to eliminate 7 wastes, and by implementing it on lean six sigma methodology could control and optimize the quality, productivity, and efficiency of industrial organization, it also has a positive effect on overall performance. Standard operating procedures (SOP) are typically used by manufacturers to document how a process is carried out. Document Standard Operating Procedures (SOP) to maximize efficiency and reduce wasted time and resources, monitor the success and failures of SOP and get rid of the 7 primary types of waste as known as asset Downtime minimization:

1. Defects: Avoid defects and low-quality rate output.
2. Overproduction: Don’t produce more than the customer required amount.
3. Waiting: Prevent all unplanned downtime or wait time.
4. Transportation: Eliminate unnecessary distance traveled from one location to another.
5. Inventory: Get rid of insufficient storage management.
6. Motion: Avoid excess movement by operators and equipment that don’t add value.
7. Overprocessing: Remove any processes that don’t add value

2.3 Integrate the SMED methodology with Lean Six Sigma

The SMED system application seeks to maximize the utilization of equipment, facilitates small batch sizes, decreases manufacturing time, and reduces downtime. In particular, preparation shortening, system adjustment time, and stock reductions As a supportive paradigm for problem-solving, the Lean Six Sigma began to use the DMAIC cycle and to combine all theories with SMED methodologies. Simultaneous use of such techniques can make the production procedure more efficient and more beneficial so that its synergy can be enhanced. Rather than concentrating on processes where the problems arise, it is much more efficient to establish the root causes of the problems. [13] For instance, the Six Sigma DMAIC methodology is a combined SMED method to apply to further eliminate setup times. Before DMAIC-Define phase using value stream mapping analysis to define selected SMED objectives which obtained KANO diagram to identify customer demand, then DMAIC-Measure phase applied OEE(Overall Equipment Effectiveness) and Pareto diagram to analysis determine the problematic equipment in SMED process that must be focused on, after that, DMAIC-Analyze phase analysis the problems and optimize improvements on SMED procedures by using 5W1H and/or FMEA techniques, furthermore, DMAIC-Improve phase on SMED methodology using ECRS and DFSS to achieve improvement implementation feasibility study, finally to standardize the changeover time and eliminate downtime analysis and quality control of SMED progress in DMAIC-Control phase by using control chart, 5S or SOP(Standard Operating Procedures) technique. Based on the Lean Six Sigma SMED implementation process described in the above, a SMED model based on Lean Six Sigma is proposed as shown in Figure 2.10, which is divided into 5 stages as shown in Figure 2.10 :

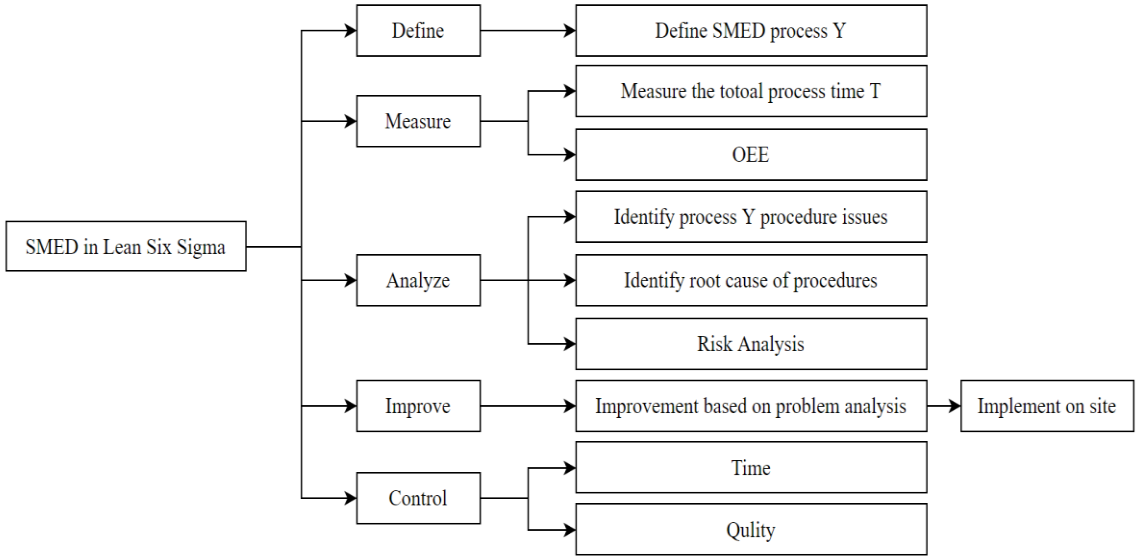


Figure 2.10: Integrate SMED methodology with Lean Six Sigma

2.3.1 SMED methodology in Lean Six Sigma DMAIC-Define phase

Since the combination of tools can be practically infinite in the SMED phase, it leads to regular adjustments in the tool process of their integration. As in some situations, changes occur between very various sizes, this sort of tool change takes a lot of time. It is possible therefore to recognize that there are incentives for improving SMED in Six Sigma DMAIC management, according to changeover time recognition and losing monetary value via tool changes assessment.[5]By considering that, we could identify the tools change, changeover time and monetary loss as customers concerning, therefore to generate customer satisfaction after traditional SMED into Lean Six Sigma SMED is must be. The expectations and production desires of customers are changeover time reduction. What satisfied customers want in the past, and what we expect now will not fulfill the minimum expectation of customers in the future. However, it is essential to ensure that strategic goals are upgraded and achieved, to periodically monitor VOC(Voice Of Customer) by using the Kano model at random times. The KANO diagram in the DMAIC-Define phase is also linked to manufacturer multi-generational innovation such as SMED methodology. The SMED methodology in the lean Six Sigma DMAIC-Define phase created SMED team aims to identify quick changeover objectives and the purpose of SMED is to minimize total production time and cost analysis and customer's benefits, etc. During the defined phase in SMED methodology, the process defined as Y, then sub-divided into Y_1, Y_2, to Y_n, and also could use the Gantt chart to manage each sub-divided process operated by team members. The team managers or facilitators by using Lean Six Sigma to define and analyze the time required for setup and changeover in the SMED process, and conduct a definition analysis, such as change the selection longest process Y_n in process Y as defined phase object to achieve improvement to complete the optimization and implementation of the production line.

Generally, the changeover time in the SMED process refers to the end of the last qualified product or process of the previous product A to the end of a qualified product or process of the following product B. The interval in between is called the changeover time. Since the changeover time classified as Non-add value activity, it should be shortened as much as possible according to customer expectations to reduce waste. The SMED process is shown in Figure 2.11 below, it includes internal activity and external activity. External activity refers to the work that can be performed while the machine is in operation, while internal activity refers to the work that must be performed after the machine stops working. External activity time(T_{ex}) can be divided into preparation time(T_p)and finishing time(T_f). Internal activity time(T_{in}) can be divided into an actual operating time such as machine stop time(T_{stop}), checking the time(T_c), and N unit molds required exchange time(T_{all}) that includes every exchange i_{th} process time(T_i) and debugging time (T_{debug}) may consist j times debug process time(T_j). In the actual operation process, there may be many different situations.

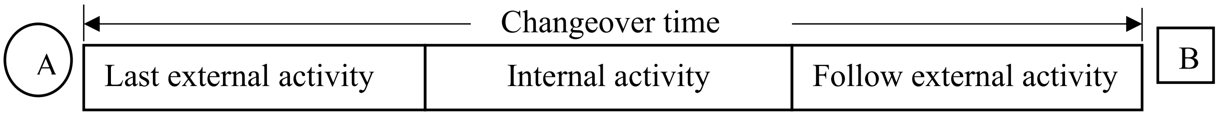


Figure 2.11: Changeover time bar chart

In the first case, the changeover time can be defined by SMED team members according to actual machine operation time, so the total changeover time(T) could be:

$$T = T_{in} + T_{ex} \tag{2.6}$$
$$T_{in} = T_{stop} + T_c + T_{debug} + T_{all} \tag{2.7}$$
$$T_{debug} = \sum_{j=1}^{n} T_j \tag{2.8}$$
$$T_{all} = N \sum_{i=1}^{n} T_i \tag{2.9}$$
$$T_{ex} = T_p + T_f \tag{2.10}$$

The second case is in a human parallel operating situation, which means two operators are carrying out at the same time, in this case, the N unit molds required production time(T_a*) is considering A operator required operation time at the ith process(T_{Ai}) and B operator required operation time at the kth process(T_{Bk}), thereby, the total changeover time(T*) could be:

$$T^* = T_{in} + T_{ex} \tag{2.11}$$
$$T_{in} = T_{stop} + T_c + T_{debug} + T^*_{all} \tag{2.12}$$
$$T_{debug} = \sum_{j=1}^{n} T_j \tag{2.13}$$
$$T^*_{all} = N[\max\left(\sum_{i=1}^{n} T_{Ai}, \sum_{k=1}^{n} T_{Bk}, \dots\right)] \tag{2.14}$$
$$T_{ex} = T_p + T_f \tag{2.15}$$

2.3.2 SMED methodology in Lean Six Sigma DMAIC-Measure phase

In the Measure phase, to evaluate the current changeover time, need to record every action during the step-by-step changeover process and combined with the on-site recorders to record the total time T in detail of each changeover process and measure the input and output of the changeover process. Then analyze the changeover progress, identify the transformation sequence of Y, and analyze the gap for improvement and ways to optimize changeover time. It is necessary to record not only the movement of the operators, the time of the changeover but also the movement and time of other assisting personnel, as well as the transportation path of the changeover tool and the walking distance of the operators if necessary. The SMED methodology in the Lean Six Sigma measure phase also requires OEE(Overall Equipment Effectiveness) OEE is a common criterion that includes three factors that contribute to technological availability, performance efficiency, and quality rate in the efficiency of the equipment. In order to facilitate the monitoring of the evolution of machine performance over time, the OEE measurement of the machine was proposed as an enhancement to improvement work. To measure the OEE, the SMED process records and the equipment stops need to be analyzed. This analysis is performed forward and formulas are applied in section 2.2.2. The determined OEE percentages will show that the operation of the equipment in Lean Six Sigma has some aspects that SMED can improve and that the primary cause of low efficiency is the high volume of micro stops that last less than 5 minutes, and the lowest percentage factor that may contribute is the performance. The machine performance is definitely affected by many stops over 5 minutes, and its causes should be recorded and assessed.

In the SMED process, the mold needs to exchange so the machine must be stopped. The longer the stop time, the lower the defined production capacity. Therefore, failure and shutdown losses affect OEE in the SMED process, and there are other influencing factors such as preparation and commissioning losses, idling and suspension losses, low-speed losses, quality defects and rework, and start-up losses. Its relationship with total production time and net production time is shown in Figure 2.12 below.

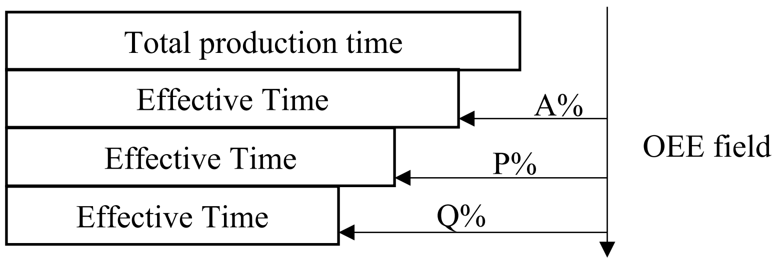


Figure 2.12: Relationship between total production and effective time

It can be seen from Figure 2.12 that the effective production time(T_{effect}) is much less than the total production time(T_{total}). The factors that affect the total time including equipment failure, shutdown preparation, and debugging, equipment idling and slow speed, product defects, and rework start-up timeliness. In general, availability, equipment performance, and production quality have impacts on the total time. Based on Lean Six Sigma and SMED methodology combination, availability and performance are the main considering, and the quality is assumed to be constant. Then the OEE calculation formula based on Lean Six Sigma and SMED methodology combination is:

$$OEE\% = \frac{T_{operate}}{T_{total}} * \frac{T_{effect}}{T_{operate}} * 100 = \frac{T_{effect}}{T_{total}}\% \tag{2.16}$$

$$T_{effect} = T_{total} - NT_{in} \tag{2.17}$$

This calculation formula is used to calculate the impact of changeover time on equipment utilization. Under other constant conditions, only the internal activity time will cause the equipment to stop. Therefore, the shorter the internal activity time, the less the mold exchanges, and the higher the equipment utilization that could achieve better OEE in the SMED process.

In the SMED process, the setup time has improvements possibilities under Lean Six Sigma methodology, the reason is the setup time depends on the operator's efficiency and engagement, also some setup conditions do not consist of a standard. Therefore, it is possible to used Lean Six Sigma and SMED methodology to measure setup improvements. According to SMED team recording, it is possible to improve by using spaghetti diagram analysis to optimize the operator's movements under Lean Six Sigma management. The efficiency of the SMED process transformation internal activities into external activities(EPZ) could be in relationship with T_{in}, T_{ex} and internal activities saving time T_{ut}:[10]

$$EPZ = \frac{T_{in} + T_{ut}}{T_{in} + T_{ex} + T_{ut}} \tag{2.18}$$

The efficiency of improvements (EUZ) can be measured as:

$$EUZ = \frac{T_{in}}{T_{in} - T_{ut}} \tag{2.19}$$

So the overall manufacturing efficiency under Lean Six Sigma and SMED methodology combination(ELSM) can be measured as:

$$ELSM = EPZ * EUZ = \frac{T_{in}}{T_{in} + T_{ex} + T_{ut}} \tag{2.20}$$

It is possible to use Lean Six Sigma and SMED methodology to lower EPZ to achieve better production results because it means that the majority of internal activities were transformed into external activities. A similar situation is also for EZ. The lower EUZ is better because it means that the setup improvements reduced the time of internal activities. [10]The obtained improvement results under Lean Six Sigma could be further considering ergonomics to achieve impressive innovation.

2.3.3 SMED methodology in Lean Six Sigma DMAIC-Analyze phase

SMED methodology in the analysis phase needs to analyze the created team recorded time and actions in detail, enhance the involvement of the process and the issues, and find the root cause of changeover. Besides, in the analysis process, operators must clarify which are the external changeover activity and which are the internal changeover activity. Then to identify the problems that exist in the current SMED process listed in the 5W1H method as shown in Figure 2.13. Process FMEA also called P-FMEA could be obtained in SMED methodology to analyze the potential failure mode and root cause analysis in Lean Six Sigma procedures. It aims to satisfy both optimize changeover time and ensure the product quality, so the SMED process is regarded as a failure mode in Lean Six Sigma since P-FMEA is a methodology approach used for identifying risks on manufacturing process changes.

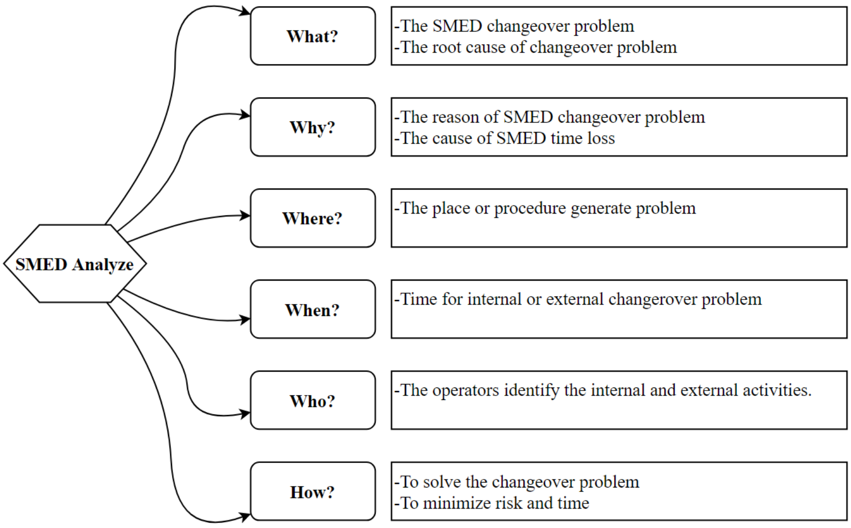


Figure 2.13: SMED in Lean Six Sigma DMAIC-Analyze 5W1H

In this phase, the SMED team members use Lean Six Sigma P-FMEA analyzes SMED process risk by the RPN scoring model. RPN variables O, S, and D are usually determined on the 10-point scale, with higher O and S indicators indicating increased occurrence and severity respectively, while D is in an inversion order, i.e. the higher the value of the detection value, the less probability of failure mode detection, which results entitles overall RPN values between 1 and 1000. [14] RPN is mainly used to rank the effects of failure modes. Specific values are used less. Most companies will set a minimum value of RPN, all failure modes greater than this value need to be improved. When the RPN values are equal, the effect of an S parameter is higher. The major root causes identified in the Lean Six Sigma analysis phase SMED process have been shown in Table 2.3. Proper classification of root causes of waste is the vital point in undertaking an improvement process. The defined team deployed and implemented the optimal process management measures when the root causes were identified. [15]

Table 2.3: Root Cause analysis

	SMED Process root cause analysis
1	Lack of visual controls
2	Poor teamwork and communication

3	Absence of set targets
4	No external steps used
5	Wasted time on useless steps
6	Deficit of workforce
7	Shortage of appropriate tools used

Based on the Lean Six Sigma analysis tool P-FMEA analysis, the steps to analyze the failure process of the SMED process are as follows:

1. Independently establish a group of professionals in the SMED team or conduct Lean Six Sigma training for the members of the SMED team, so that they can have different functions or not in the same department, thereby standardizing the teamwork structure. The trained professionals in the team establish evaluation indicators to analyze the entire process of mold change and determine the failure assessment during the SMED process.
2. Since the multi-index evaluation model is established, a failure mode may involve multiple evaluation indexes. Then which index is the core index and how much influence the failure mode of each index determines will determine the final influence of the failure mode on the mold change process. Therefore, it is necessary to determine the weight of each indicator, including primary indicators and secondary indicators. It is determined that the severity, frequency, and detectability of the failure mode determined by each index must be determined, and the S, O, D of the failure mode determined by different evaluation indexes shall be established.
3. After the weight and influence of the evaluation index are determined, the final S, O, D of the failure mode can be determined. When a failure mode is determined by multiple indicators, the weighted average method is used to determine the final S, O, D. If it is determined by an index, then the S, O, D of the failure mode is its S, O, D number under the judgment of this index.
4. Calculate the value of RPN, draw the P-FMEA table, and determine the degree of influence of each failure mode.
5. According to the severity(S) of the failure mode, propose improvement and optimization measures, and determine the improvement plan.

2.3.4 SMED methodology in Lean Six Sigma DMAIC-Improve phase

The Lean Six Sigma DMAIC-Improve phase is much important, it combining the principle of SMED methodology. For each root cause generated by the previous phase a proper improvement has been found in the SMED process and implemented with the Lean Six Sigma analysis phase. The analysis of the data obtained during this phase and the previous phases have not only established the correct strategies of brainstorming and regular feedback but also continues to optimize and summarise.

Improve based on DFSS and ECRS and the S(severity) parameter of RPN scoring has been analyzed, improvements are made in sequence, and finally implemented on current progress. In terms of shortening time, it is commonly used to combine the external changeover activity and the internal changeover activity. By repeatedly using the 5W1H questioning method from the previous phase, extend to convert the internal activity to the external activity. The desired result was almost achieved during the improvement phase by being oriented by the SMED methodology in Lean Six Sigma.

After setup time reduction discovered by P-FMEA assessment, it could be further improved by indicates the effectiveness of corrective actions, and Lean Six Sigma improve phase can be used to verify the analyzed value of performing P-FMEA. To calculate after improvement RPNs, the SMED team may assign a second set of severity, occurrence, and detection ratings for each issue by using the same rating scales and multiplies the improved ratings to calculate the modified RPNs. The effective percent improvements for a reduction in RPN can be calculated as follows:[16]

It is also possible to propose the Analytic Hierarchy Process(AHP) into SMED methodology to help decision-maker in choosing the best solution throughout the improvement process of SMED implementation. By providing technique in identifying, weighing criteria, and analyzing the data collected from the SMED team, AHP can facilitate the decision-making process. AHP also can reduce bias in decision making by capturing both subjective and objective evaluation measures and thus offers a beneficial mechanism to improve the SMED process under the Lean Six Sigma methodology.[17] The SMED process during the improvement stage of Lean Six Sigma, by using AHP to choosing the best and most suitable improvement strategy for reducing changeover time.

2.3.5 SMED methodology in Lean Six Sigma DMAIC-Control phase

This Lean Six Sigma DMAIC-Control phase for SMED methodology focuses on continuous improvement, and to set out standard changeover time and changeover actions are important. Analyze and evaluate the effects of quick changeover. Anything an enterprise does is for profit, and shortening the changeover time may require a lot of time and cost. Therefore, the enterprise must change the mold quickly when the mold change time can be shortened to achieve greater profits. Hence, it is necessary to balance when to adopt rapid changeover, and to control the stability of the entire SMED process. By using improvement Lean Six Sigma 5S technique is aimed to control and monitoring the whole SMED control phase meanwhile make improvements from small to sustainable, also SOP(Standard Operating Procedures) to do problem-solving standardized methodology which helps in recording and visualizing the entire SMED process of quality control in Lean Six Sigma. This significant phase forward in standardizing and completing the SMED transformation into Lean Six Sigma. Once the SMED method has been visually recognized, along with all the employees involved, it could be further recorded and attempt to classify losses digitally. The indirect benefits of the SMED task would be illustrated by enhanced standardization of the Lean Six Sigma management process, increased customer satisfaction expressed by improved flexibility of Changeovers, better teamwork, and better distribution of full-time equipment. To adopt the efficient Lean Six Sigma manufacturing approach, a need for enhanced collaboration in the SMED phase between operators and between operator-supervisor has been identified.

After the implementation of SMED and Lean Six Sigma combination, firstly, the changeover time should be greatly shortened, and secondly, not only the changeover time is required to be reduced, but it must be stabilized in an acceptable range. Randomly record the changeover time after multiple exchange procedures are improved, taking into account the characteristics of random sampling, if the number of samples is n, the average changeover time $\bar{x}$ about the ith changeover time x_i and standard deviation σ could be calculated as:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2.21}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}} \tag{2.21}$$

After the changeover time mean value $\bar{x}$ and standard deviation σ is known, based on the central limit theorem which criteria is normal distribution, the control limits would be[18]:

$$UCL = \bar{x} + 3\sigma \tag{2.22}$$

$$LCL = \bar{x} - 3\sigma \tag{2.23}$$

$$UCL - LCL = 6\sigma \tag{2.24}$$

A control chart is generally made up of three horizontal lines and one vertical line as shown in Fig. 5.2, the probability between UCL and LCL interval is 99.73%, so the small probability events that fall outside should not happen. If there are variability data in the data of the sampling inspection, we must analyze the causes of the occurrence in combination with the specific conditions, and then make further improvements. Further improvements are expected in this control phase and the main focus of the control is on establishing and standardizing compliance and earnings upgrades. Communication, discipline, process time, and quality control are major factors in the success of a future revolution.

3. Analysis of Ergonomics and SMED methodology combination

The word of Ergonomics came from the Greek language, it literally means the law and work. Ergonomics is a very broad and multidisciplinary field of study that embraces different disciplines such as Anatomy, Physiology, Occupational, Medicine, Medicine, Psychology, Design, Architecture, and Engineering. For many theories, ergonomics and human factors are and should be, related. Others point out that ergonomics, which was originally developed in Europe, is firmly grounded in biology, with a research focus on equipment and workspace design, whereas Human Factors, which first emerged in the USA, has its theoretical origins in psychology, with a strong emphasis on the integrating of human concerns into the overall system process. Ergonomics is a science concerned with the design centered on human necessities and a profession that applies the theory, concepts, data, and design methods for achieving human well-being and overall system efficiency. To compatible with human needs, strengths, and weaknesses, ergonomists contribute to the development and assessment of tasks, work, services, environments, and systems. Physical ergonomics is concerned with human physiological, anthropometric, anatomical, and biomechanical features as they contribute to human physical exercise. The anthropometry specifies the relevant physical dimensions of a population of users such as population in ergonomics are always used in a statistical sense, its main objective is designed to accommodate as wide a range of users as possible. Two main categories of anthropometric data are of interest for ergonomists are Structural Anthropometry which is in static dimensions and Functional Anthropometry which is in dynamic dimensions. Anthropometric data are organized for gender and age groups which in particular, adults, 18 years up, and children of different ages. Behavioral Ergonomics is concerned with mental processes, such as perception, brain, thinking, and motor response, as they influence interactions between humans and other system components. Organizational ergonomics is responsible for optimizing socio-technical frameworks regarding their structures, strategies, and procedures in the organization. This section will be considering physical ergonomics within SMED methodology.

3.1 Introduction of Ergonomics assessment

Musculoskeletal Disorders (MSDs) refers to a wide variety of inflammatory and degenerative issues involving the muscles, tendons, nerves, joints, limbs, peripheral nerves, and supporting blood vessels. These include neurological disorders such as joint inflammation and associated conditions (tendinitis, tenosynovitis, epicondylitis, bursitis), Nerve stress disorders (carpal tunnel syndrome, sciatica), osteoarthrosis, and neurovascular disorders (white finger-Raynaud syndrome, thoracic outlet syndrome) as well as less standardized conditions such as nausea, low back pain, and other localized pain. The most frequently involved body regions are the neck, low back, shoulder, forearm, and hand, while recent attention is also being called to the lower extremity. For MSDs, considering only the prevalence has several limitations. The latency of MSDs may be a long time.

Also, MSD is quite common (especially back-pain) and can be developed outside the work environment. Longitudinal studies over long periods are more effective. But they are difficult and costly to carry out. Main occupational factors are Force, Posture, Repetition, Duration, Work organization, Contact stress, and vibrations. In workplace ergonomics, it is important to compute the level of risk associated with a certain work task. By using a formula to analyze with a good awareness of workers' capacity and measure with good accuracy the task demand.

$$Risk\ Index = \frac{Demand}{Capacity} \tag{3.1}$$

The psychophysical measurement is the level of effort as perceived by operators. The level of effort can be subjectively assessed using the Borg Scale, it is important to rate the effort way to be performed, which includes the influence of posture. The Table 3.1 shows the Borg scale scoring model.

Table 3.1: The Borg Scale

Score	Perceived extension
0	Nothing
0.5	Extremely weak
1	Very weak
2	Light
3-4	Moderate
5-6	Heavy
7-9	Very strong
10	Almost maximal

Pain, fatigue, and MSDs may result from sustained inadequate working postures that may be caused by the operator's poor working situation. In general, postures are to be analyzed both as extreme values such as static postures, if held for 4 seconds or more, or dynamic movements if repetitive, and as cumulative values over time. ISO 11226 and EN 1005-4 standards specify acceptable, conditionally acceptable (about duration and breaks), and not acceptable conditions. The inappropriate postures as shown in Table 3.2. Mostly postural stress can be reduced by redesigning the workplace to improve posture and a good work-tool design may be effective in reducing task-induced stress. Table 3.3 shows a repetitive frequency classification.

Table 3.2: List of Awkward postures

Awkward postures	Conditions
Trunk	Avoid extension Avoid Flexion≥ 60° Avoid sideways bending or twisting ≥ 10°
Neck	Avoid extension Avoid Flexion≥ 40°,better < 20° Avoid sideways bending or twisting ≥ 10°
Elbow	Avoid winger flexion High supination Pronation simultaneous to grasp
Wrist	Avoid flexion/extension ulnar/radial deviation simultaneous to grasp
Fingers	Avoid to hold and push with fingertips Avoid extending the thumb

Table 3.3: Operator repetitive movement classification

Score	Classification
0	No regular load
2	Very low movements or long breaks
4	Slow regular load or frequent breaks
6	Regular load or breaks not frequent
8	Rapid movement or breaks not frequent
10	Rapid load or difficulty with work pace

The recovery periods also means the duration of work which contains breaks and periods of inactive work. As an appropriate rule, the ratio between work and recovery periods should be 5:1, an optimal condition would be having 5 to 10-minute breaks at the end of each working hour. The risk assessment during the operation process utilizes checklists as well as ergonomic screening tools as they allow for a rapid risk evaluation. Table 3.4 shows the legal requirements of risk assessment methods.

Table 3.3 Risk assessment methods analysis

Type of working activity		Method for risk assessment	Reference standard	Target body segment
MMH (load>3kg)	Lifting tasks	NOISH	ISO 11228-1 EN 1005-2	Back
	Push/Pull&Carry	Snook&Criello	ISO 11228-2	Back and shoulders
Handling of low loads at high frequency		OCRA checklist	prEN 1005-5	Upper limb, wrist, elbow, joints
		OCRA Index	ISO 11228-3	

Whole-body risk assessment methods can successfully be used for the analysis of postures during Manual Material Handling(MMH). For Examples:1.OWAS (Ovako Working posture Analyzing System) as shown in Table 3.4 which was developed in 1997 by Karhu, Kansi, and Kuorinka, 2. REBA (Rapid Entire Body Assessment) was established in 2000 by Hignett and McAtamney, 3. PLIBEL was developed in 1995 by Kemmler. Whole-body posture is described by a four-digit code, indicating the position of the back (4 postures), arms (3 postures), legs (7 postures), and weight to be handled (3 categories of weight). OWAS does not have any definition of a fundamental mathematical model, rather it depends on a lookup table that translates four-digit posture codes to Action Categories as shown in Table 3.5. As with many other risk assessment techniques, OWAS is based on screenshot evaluations of single postures, often those considered to be dangerous or hazardous Frequency and weighting of measurements are feasible but time-consuming and often present additional difficulties in interpretation.

Table 3.4: Action category

Action Category	Action Required
AC 1	No action required
AC 2	Action required soon
AC 3	Action required ASAP
AC 4	Action required immediately

Risk assessment of NIOSH lifting equation to evaluate sagittal plane lifting on is the task and workplace organization, regardless of worker's characteristics. Only through biomechanical modeling, is it possible to take into consideration body size. Also, the level of compression on the spine may be computed taking into account the actual posture of the operator. However, in biomechanical models, the effect of frequency is disregarded. The revised NOISH has been developed in 1994, it considering maximum mass recommended by NIOSH under optimal lifting conditions (sagittal plane, occasional lift, good coupling, vertical lift D within 25 cm). Thought to be safe for 99% of male healthy adult workers and 75% of female healthy adult workers. The Recommended Weight Limit (RWL) is:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \qquad (3.2)$$

The multiplication of the above six coefficients is less than 1, then taken to minimize the RWL must take into account the task reasons that affect a divergence from the ideal scenario.

3.2 Ergonomics study within SMED methodology

Since the SMED technique ensures a fast and efficient changeover product to the following. It has a changeover time, which is the cumulative time between the last of the current product and the first of the following. The Lean Six Sigma DMAIC methodology may already appropriate improve SMED system, it represents the key factor into a rewarding small lot size production items, which would ensure to improve product flow and make it more flexible. Beyond the economic value-added benefits, by decreasing the changeover time further Non-added value achieves better ergonomics conditions. However, it is possible to reduce the setup time in the SMED process and at the same time improve ergonomic conditions. The high setup time will be affected by issues with productivity and disruptions for customers. According to the SMED technique and rising ergonomic requirements, the setup time would be reduced and risky MSDs would also be reduced.[15]

The links between Ergonomics and the Lean production method are pointed out to enable those to be discussed simultaneously.Besides, synergism between Lean and Ergonomics can be attained. But lean processes can unintentionally make highly work repetitive, thus removing essential time off for laborers. Employees are impacted by repetitive tasks as stressful postures and high strengths are repeated during the day. In the long term, economic benefits resulting from productivity growth and quality improvements can be used to pay higher rates for workers' compensation for musculoskeletal disorders (MSDs). Appropriate factors to minimize setup times and to improve ergonomic conditions were carried out using the Lean manufacturing SMED technique and ergonomic analyses. Regarding ergonomic conditions, the first step for the selection of a multifunctional SMED team would choose a postural analysis system such as OWAS which it classed as shown in table 3.5 and REBA levels are shown in table 3.6, to evaluate the level of MSDs risk since it provides a score ranking system for muscle activities caused by dynamic, static, rapidly changing or unstable postures. The SMED process selected team would assess the level of MSDs risks by 4 main critical postures regarding ergonomic conditions[19]:

- Postures P1: Machine equipment replacement
- Postures P2: Use of tools with poorly ergonomic handles
- Postures P3: Difficult machine connect
- Postures P4: Programming controlled machine

These the above postures selection was made based on the operators' opinions.

The EAWS (European Assembly Work-Sheet) ergonomic screening method was developed from OAWS to comply with all parts of the UNI EN 1005 standard series and the corresponding ISO standards such as UNI EN ISO 11228.

Table 3.5: OWAS classification

Back	Arms	Legs	Load
Straight 1	Both below shoulder hight 1	Sit 1	<10 kg 1
Bent 2	Single above shoulder height 2	Stand on both Straight legs 2	10-20 kg 2
Twist 3	Both above shoulder height 3	Stand on single straight leg 3	>20 kg 3
Bent & Twist 4		Stand on both bent leg 4	
		Stand on single bent leg 5	
		Kneeling 6	
		Walking 7	

Table 3.6: REBA action levels

Action level	REBA score	Risk level	Action
0	1	Negligible	None necessary
1	2-3	Low	Little necessary
2	4-7	Medium	Necessary
3	8-10	High	Medium Necessary
4	11-15	Very High	High Necessary

When ergonomics conditions come to the SMED manufacturing process, the target is to minimize setup time and to increase productivity by making the workstation comfortable for the operators. The three main impacts on lean manufacturing by considering ergonomics would be:

1. Muda(Waste): unnecessary body movements or material handling, idle times
2. Mura(Inequality): line unbalancing, reachability problems for small size workers
3. Muri(Unreasonableness): awkward postures, strength requirements, incorrect grips

Settings are split into internal and external operations in the SMED methodology. During the regular operation of a process, external activities may be carried out while still operating. For example, before the machine is stopped, this can prepare the equipment for setup operation. Internal activities can only be done if the machine shuts down, for example, install or disable the changing dies. Internal and external activities of setup including planning, adjusting after-processes, materials control, installation and removal of tools, adjusting settings and sizing brakes, measuring, test runs, etc. The SMED process steps could be shown in figure 3.1. The initial step is composed of identifying all the activities needed to execute a setup. This was performed by Phase 3 for using a video recording to collect activities and times data. In the 1st step, the aim was to define and distinguish internal and external activities. The 2nd step was planned to simplify these internal tasks further. System design, operation automation, and operator coordination, and synchronization are typical activities at this moment. Besides, the 3rd step is aimed at simplifying external activities. Subsequently, it is a possible flowchart with the methodology to be followed for the implementation of the SMED tool that explores ergonomic factors may be presented.

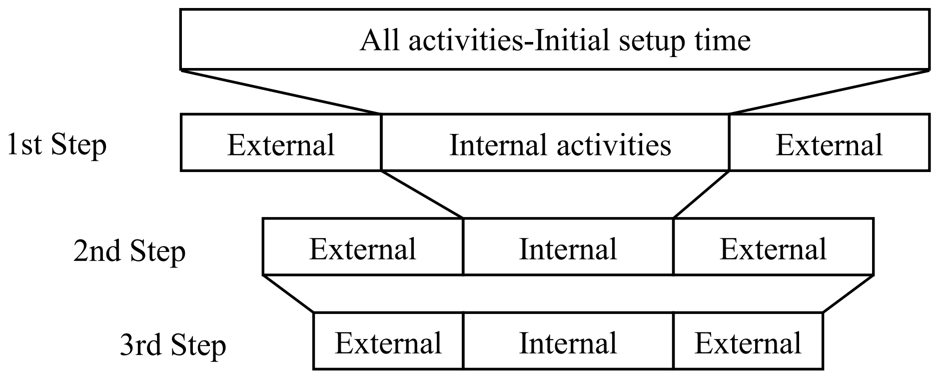


Figure 3.1: SMED process steps

A Flowchart can be created to take these measures into account in the Ergonomic conditions for the combination of the single minute die exchange system (SMED). The figure 3.2 flow map for ergonomics study in SMED methodology would be considering both in minimize setup times and mitigate ergonomic risks. It will show that synergism can be accomplished between Lean and Ergonomics. The Ergonomics study in SMED methodology flowchart established in The following is revolutionary because it incorporates Ergonomics with a SMED tool and can be used by experts in any production field. [19]

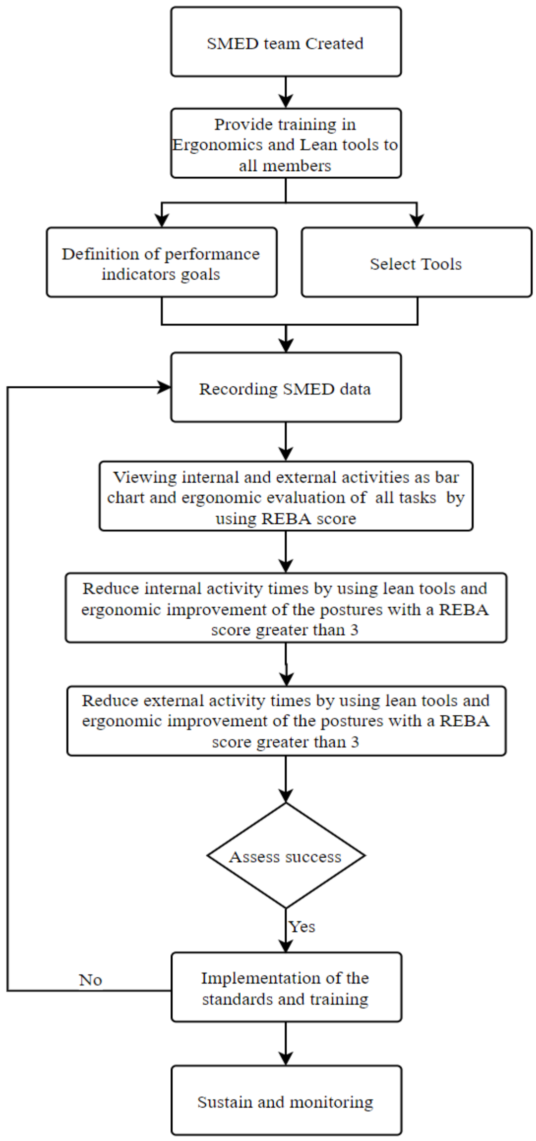


Figure 3.2: flowchart for ergonomics study in SMED methodology

3.3 Implementation analysis for Ergonomics and SMED methodology combination

3.3.1 Integrating SMED methodology and ergonomics for Setup reduction

Regarding the critical postures P1 of machine equipment replacement, the ergonomics condition improvement could be the implementation of a container cart to eliminate the trunk flexion while the external activity of replacing the equipment of the machine. Figure 3.3 shows Swivel wheels have good ergonomics and should be on the same side as the handle, larger wheels mean less strength is required to push or pull the cart, but ensure wheel maintenance such as wheel lubrication, cleaning and repair regularly regarding lean 5S quality methodology to sustain economic and efficient manufacturing process.

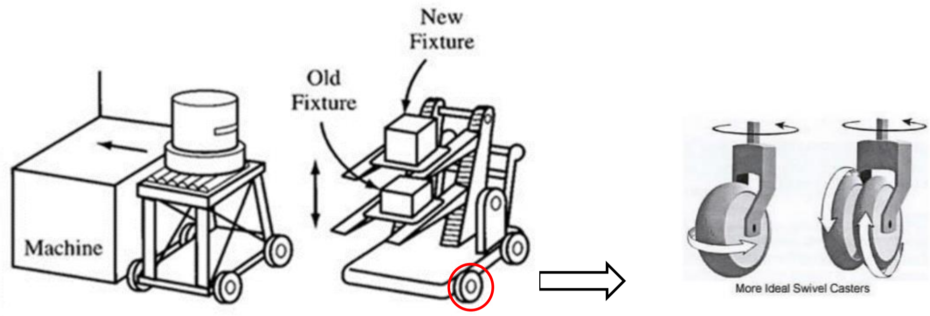


Figure 3.3: Ergonomic machine equipment replacement

The operators using swivel wheel carts to achieve better good ergonomic operation condition, After it improves the physical MSDs risk was reduced from very high to low, the REBA score would be reduced from 12 to 3.[19]Furthermore, this improvement increases the productivity of operation and significantly reducing operation time.

Regarding the critical postures P2 for MSDs risks ergonomic condition, figure 3.3 shows one of the measures undertaken was to replace the weak ergonomic condition tool called “L shape handle”, with another one which was more ergonomic and agile, called “Ergonomic T shape handle” wrench. This development resulted in an efficiency increase in this activity by reducing the time required to accomplish the tightening and loosening screw operations.[19]

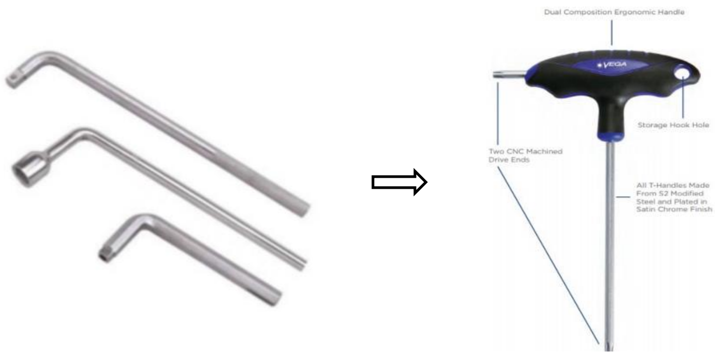


Figure 3.4: L shape handle versus Ergonomic T shape handle

By replacing the L shape handle with an ergonomic T shape handle in the general line production SMED process, it would reduce the REBA score from 7 to 5.[20]It will be effective to improve SMED phase 5 for external activities and reducing operation time, furthermore, it could be proposed automated procedures instead of manual handle operations, but this would be cause high financial support, regarding change tools economy, the automated procedures are not proceeding. The operation team analyzed two awkward postures regarding critical postures P3 is related to the difficult access to the machine and P4 difficult to programming control the machine in SMED phase 3 showed in figure 3.5, which are awkward to access and so high that push arm lifting above 45° for a long period. The posture P3 in the SMED process is regarded as difficult to access the machine, the trunk flexion had a REBA score of 10 and it means a high-level risk of MSDs. The posture P4 to programming machine that forces arm lifting above 45° had medium MSDs risk for a REBA score of 5. It could be proposed several machine changes to solve these ergonomic problems, such as using a robot and lowering the command box.

Figure 3.5: Awkward postures P3 and P4

Below Table 3.7 summarize the operation gains and the REBA score of the before ergonomic improvement situation and the situation after the ergonomics improvements described in the SMED process.[19]

Table 3.7: Summarize REBA score for operation gains in SMED

Postures	REBA score before	REBA score after	Operating Time Before(sec)	Operating Time After(sec)	Saved Time (sec)
1	12	3	396	300	96
2	7	5	144	108	36

Regarding the SMED process phase 3 for the document, by recording all the setup activities, the SMED operation team is together to deep analyze all the activities. In 1st step of the SMED process, they will identify the internal activities that could transfer into external, such as data collected, machine programming, and the delivery from the previous setup to the quality control function. The 2nd step was to simplify internal activities through the integration of such paths, such as the removal of transport and the movement of tools currently within control, etc. Considering at this point the use of ergonomic tools for enhancing, as well as other strategies to simplify internal activities. All these enhancements have resulted in a decrease in the number of internal activities and as a result, a reduction in set-up time can be achieved. The 3rd step was the simplified representation of external activities. One of the measures taken at this step was the elimination of many movements and the transport of tools. Along with enhancing the programming operation of the computer by employing an ergonomic condition for the operator.

It is very necessary to clarify efficiency measures while at the same time adopting changes in the workshop. On the other side, tasks are more repetitive, contributing to musculoskeletal disorders, increased absenteeism, and decreased productivity. According to the assessment undertaken out using the REBA process, the risk level of MSDs was restricted (ex. REBA risk level of the Posture P1 was reduced from very high to low). This means that the combination of ergonomics and SMED methodology principles of development considered in the lean manufacturing phase leads to the achievement of successful production activities.

4. Analysis of Lean Six Sigma and Ergonomics combination in SMED

The benchmarking that some businesses are now pursuing to achieve organizational and service excellence is a consequence of intensified competition, internationalization, and an economic climate that makes customers more demanding about the cost of what they consume. As result companies feel the need to justify their methodologies and continually enhance efficiency in all fields (e.g. logistics, organization) by catching up with or if possible, overtaking competitors. Lean Six Sigma methodology for the SMED process has been described as the most promising programs for continuous improvement of organizations. The SMED process principle of Lean Six Sigma is a company theory and strategy to drive continuous improvement of production processes to achieve higher and more beneficial customer satisfaction. In the lean production SMED system, through the interface technology of human-machine, human-organization, and organization-technology, some ideas and improvements of people are quickly transferred to the machine and SMED manufacturing system. If advanced manufacturing systems can gradually turning into a human-centered integrated system, the flexibility and humanization of the manufacturing system will have more prominent advantages. The role of humans in modern manufacturing systems has not diminished but has become more and more important and critical. Ergonomics participates in shaping the SMED manufacturing mode in the process of realizing the technology and goals of the Lean Six Sigma production system. In the future manufacturing mode, the requirements for people are getting higher and higher, not mainly physical requirements, but mental labor and psychological requirements. In this environment, people are psychologically stressed, emotional, and their abilities are all possible. Causes unsafe factors and affects the improvement of work efficiency. Once an enterprise occurs, the loss to the enterprise is relatively large. As the main body of Lean Six Sigma SMED manufacturing, operators are also one of the key factors affecting production. In the process of pursuing the ultimate goal of Lean Six Sigma, if the human factor in the production system cannot be maximized, then this production system cannot guarantee high quality, high efficiency, ergonomics is to provide reliable guarantee and continuity for the stable demand-driven production of lean production. In the entire human-machine production system, the process can ensure the stability and high efficiency of the machine, and the organization and management can ensure the scientificity and rationality of production. Ergonomics is to ensure the sustainability and efficiency of the human factor while avoiding the human factor insecurity in itself.

The SMED method and the combination of ergonomics within Lean Six Sigma are quite visually impressive to achieving better sustainable efficiency as they concentrate on eliminating waste, uncertainty, and the productivity of production. What businesses tend to understand is the ability to further boost efficiency gains if ergonomic concepts are integrated and applied concurrently with Lean Six Sigma. The incorporation of Ergonomics in the continuous improvement process is very significant, as conventional Lean Six Sigma methods while attempting to increase efficiency by reducing resources, can easily ignore the weaknesses and needs of the human factor in the production process.

From the above chapter definitions, the well-saying philosophy of ergonomics is mainly about the relationship between operators, machine equipment, SMED process tools, and the work environment. Below figure 4.1[21], shows the traumatic injury type claim counts in the manufacturing industry, where the ergonomic conditions are not given importance well. It is important to improve and implement the human well being conditions within the Lean Six Sigma methodology in the SMED process of the general manufacturing process to decrease the injuries, avoiding MSDs and accidents to the employees.[22]

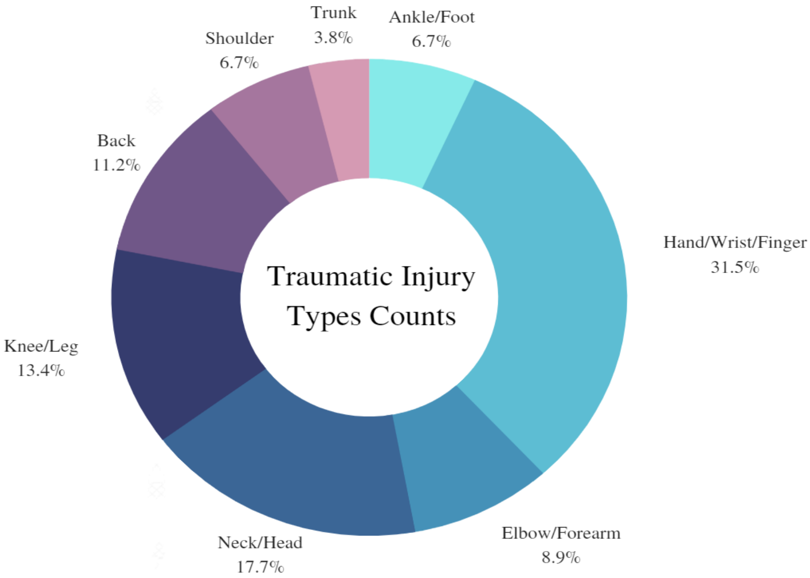


Figure 4.1: Traumatic injuries

4.1 Overview of Ergonomics in Lean Six Sigma system

Both Ergonomics and Lean Six Sigma are system-oriented approaches. However, frequently Ergonomics is not viewed by the SMED team this way. Since Ergonomics is most often housed within the Occupational Safety and Health department which is mainly to answer legal requirements and to perform risk management, managers tend to inadvertently restrict its scope of intervention to hazards, instead of benefiting from its help to improve organizational effectiveness, business performance or costs.[23] Therefore, continuous improvement processes should be performed applying simultaneously Ergonomic and Lean Six Sigma approaches coherently to ensure both gains in productivity and working conditions. As mentioned in chapter 2.2 that Lean Six Sigma results from the combination of Lean technique and Six Sigma methodologies. Ergonomics is the science that focuses on systems where the interaction between people and their environment occurs to optimize well-being and overall performance. Therefore Ergonomics can be characterized by:

1. Having a system approach

2. Being design-driven
3. Focuses on performance and well-being.

According to the above Ergonomics characteristics, the potential of Ergonomics might be under-exploited in the traditional manufacturing process. Ergonomics is mainly associated with the worker's well-being, being most often housed within the Occupational Safety and Health (OSH) department, therefore managers tend to inadvertently restrict its scope of intervention to OSH hazards, instead of benefiting from its help to organizational effectiveness, business performance or costs. [13] In fact, the value of Ergonomics is beyond health and safety since Ergonomics can add value to a company' business strategy to reach the ultimate business goal of profit or intermediate business goals related to profit drivers like cost minimization, productivity, quality, delivery reliability, responsiveness to customer demands, or production flexibility. Therefore it is necessary for the integration of ergonomics in the Lean Six Sigma methodology paradigm, which requires a re-positioning from a primary health ergonomics approach to a more systematic-oriented ergonomics approach. [24]

4.2 Integration Ergonomics and Lean Six Sigma methodology in SMED process

Many forms of literature have written about negative impacts on working conditions partially due to activities carried out during the implementation of Lean Production Management. These activities also contribute to an increase in the pace of work, workload, and work increased frequency that can influence the health and well-being of workers, such as exhaustion, tension, stress, and work-related disorders. A more comprehensive approach is needed to implement a human factors-oriented approach, as higher efficiency is required with fewer resources that can affect the well-being and performance of workers. Lean Six Sigma primarily focuses on external, e.g. business productivity, but leaves internal activities such as operator productivity is virtually ignored. Internal productivity regards the ability of workers to produce more output with no increase in the risk of traumatic injury or MSDs, which is a main concern of Ergonomics. Conversely, unwary ergonomic activities can result in unwanted effects on production performance. Therefore, an integration solution that maximizes performance combining the internal productivity concern in the overall external productivity goal is one that requires the integrating Ergonomics and Lean Six Sigma SMED methodology. The integration of Ergonomics in continuous improvement activities gives an added perspective of recognizing ergonomic issues and a whole new dimension to the improvement activities.[13] The further improvement approach for Lean Six Sigma and Ergonomic combination in SMED process are steps along the way in the evolution of Lean Six Sigma SMED manufacturing process improvement methodology, being Ergonomic conditions extra thinking build upon previous SMED process and adopting the effective aspects of Lean Six Sigma and adding. Based on this combination idea a framework is proposed to help the integration of Ergonomics and Lean Six Sigma based on the DMAIC cycle in the SMED process. DMAIC is very convenient since it was generalized as an overall framework for SMED process improvement in previous chapter 2.3. The Lean Six Sigma SMED process generalization can go further, by encompassing an integrated approach that incorporates Ergonomic principles, tools, and methods. The proposed showed in figure 4.2 the corresponding framework associates with the LSS procedures used in each phase of the DMAIC cycle with an additional ergonomic perspective in the SMED process, as following:[13]

- Define: Ergonomic assessment and data from existing SEMD process Y records which are used to characterize the initial situation of the working conditions during the SMED process and to identify further new process improvement opportunities.
- Measure: To complement the establishment of the SMED process improvement baseline, the ergonomic methodology is used to evaluate the status of performance metrics at the beginning of the SMED improvement process. These measurement data will be compared to the performance metrics at the end of the Control phase assessment success to evaluate the gain resulting from the improvement process.
- Analyze: First to identify current SMED process Y possible issues and evaluate risk analysis, then Ergonomic tools and methodologies are used to pin-point root causes affecting the SMED process Y working conditions. These root causes have to be prioritized with combined LSS methodology and selected for elimination on the subsequent Improve phase.
- Improve The selection and implementation in analyzing phase solutions which could be eliminated or, at least, mitigate the effect of root causes incorporates ergonomic activity decision and LSS methodologies which help to identify such as cost-effective solutions, test such solutions, for example, using Jack software modeling, and plan their implementation activity decision and deployment.
- Control: To sustain the assessment gains achieved during the SMED process Y, and verify improvement based on problem analysis to implement response plan on site, meanwhile a continued quality control monitoring process and training are required, which includes ergonomic conditions and Lean Six Sigma methodologies, as well as interventions to raise awareness.

It can be summarized that the combination between Ergonomics and Lean Six Sigma during the SMED manufacturing process development projects is constantly feasible and profitable for both the manufacturing process and the employees.

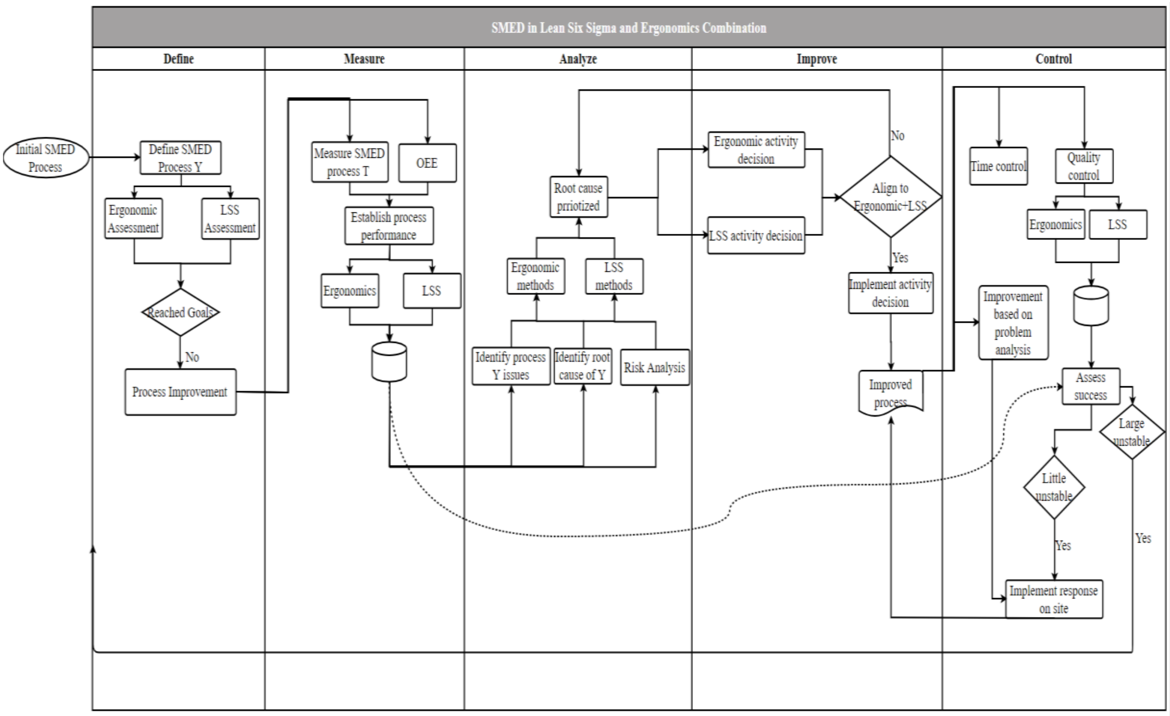


Figure 4.2: Ergonomics and LSS combination in SMED process

5. Case study: Applied to Motor manufacturing plant

Through the above analysis, it can be proposed that the combination of Lean Six Sigma and ergonomic conditions is applied to the analysis of the SMED production line of a motor manufacturing plant, and the data is analyzed through the Lean Six Sigma Minitab tool to minimize the changeover time and reduce the production cost.[25]

5.1 Motor manufacturing-Lean Six Sigma DMAIC Define phase

The case study In motor production, the lathe is used to turn the bearing holes of the AS (upper) and BS (lower) heads and the four positioning holes on the diagonal, mainly involving series motors (UM) and brushless motors (BLDC), the following Figure 5.1 shows the conversion of AS head from UM to BLDC as an example.

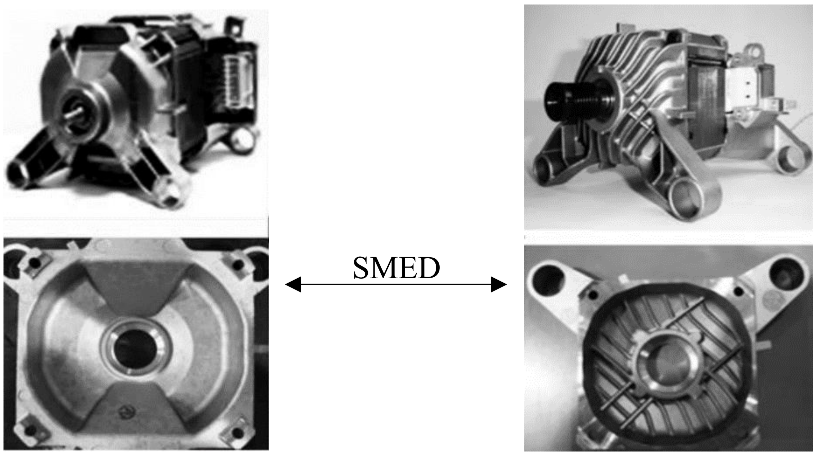


Figure 5.1: SMED example for UM to BLDC AS head

Refer to the daily report of motor production and collect the conversion data of each production line in the first half of 2013. The changeover time of a certain lathe for the universal motor to brushless DC motor is 111.9 minutes which its process showed as Table 5.1, its performance needs to be improved, selected as the research object of the Lean Six Sigma and ergonomics combination project.

Table 5.1: Operation definition for UM and BLDC

Description	Processing	Inspection	Transportation	Storage	Waiting	Duration(min)
Y1: Preparation					x	4
Y2: Change tools			x			20.9
Y3: Check bearing				x		28.6
Y4: Turning test	x					36.4
Y5: QC check		x				22

5.2 Motor manufacturing-Lean Six Sigma DMAIC Measure phase

In this Lean Six Sigma project, there are two points involved in the measurement, one is The measurement of changeover time; the second is the measurement of motor AS head quality characteristics.

5.3 Motor manufacturing-Lean Six Sigma DMAIC Analyze phase

Due to the problems of early-stage exchange and calibration, the debugging time was long and 11 pieces of scrap were produced. It can be said that the type change of the lathe completely far away to meet the requirements of the SMED perspective. On the contrary, to a certain extent, it also has an adverse effect on the production of the motor. SMED team members (including model changes, workshop directors, process engineers, equipment engineers, quality engineers, and project leaders in the continuous improvement department) need to combine Lean Six Sigma methodology to use brainstorming and P-FMEA methods from fishbone analysis as shown in Figure 2.7 before. Table 5.2 P-FMEA analyzed aspects to analyze the root causes of problems that may affect the exchange of the AS head lathe at each stage.

Table 5.2: P-FMEA analysis affecting SMED changeover time

Process	Failure mode	Failure effect	Root causes	Risk analysis				Action Recommended
				S	O	D	RPN	
Preparation	After machine stop,find change tools	No external activity/long preparation	Lack of preparation	4	8	2	64	Listing BOM, early preparation upon it
Mold Exchange	Reciprocating take tools	NAV transportation	Tools are not clear organize	4	8	2	64	Equipped with tool box or cart
	2 operators,1 is free for long	Exchange waiting	Inappropriate corporation	8	8	3	192	Arrange actions properly
	Not familiar with SMED	Long changeover time	Complex tools	4	8	3	96	Propose multi-functional tools
			Casual for exchange	6	6	2	72	Standardize operation process
			Not familiar with operation	4	4	2	32	Training by instructor
			lightness	4	9	1	36	Equipped with professional light
			limited workplace,dirty and noisy	4	9	1	36	Overcome it
Test/Calibration	Sudden machine failure	Long testing time,large scrap items	Machine failure hidden trouble	8	2	2	32	Regular and plan to maintenance
	Testing multiple times		Machine worn out	4	9	2	72	
			Poor positioning calibration	8	8	2	108	Improve tools type
			Low qualified product	8	8	2	108	Using MAHR to verify position
Measurement	Waiting for test	Long time for measurement	Waiting for quality inspector	4	2	1	8	Information disclosure
	Inappropriate measurement	Measurement duplicate	Measurement tools lack of accuracy	2	4	4	12	Regular matain mmeasurement tools

5.4 Motor manufacturing-Lean Six Sigma DMAIC Improve phase

According to P-FMEA analysis were identified, discussed, and finalized for implementation in UM and BLDC SMED manufacturing procedure. Table 5.3 shows the implementation of ECRS in relation to 5W1H for failure mode activities. Therefore, according to the results of the Lean Six Sigma Analyze phase and the implementation of ECRS for failure mode, the SMED team has formulated different improvement countermeasures as shown in the "Action recommended " column in Table 5.2.

Based on the results of the P-FMEA analysis, it could be proposed It is also possible to propose Analytic Hierarchy Process(AHP) into the SMED methodology to help decision-making to classify the improvement process of SMED implementation. Table 5.4, "×" indicates that the improvement countermeasures are desirable, and "○" indicates the key factor, and the effectiveness of the countermeasures needs to be further determined. Therefore, in this section, test design is carried out for the four improvement measures marked with "○" in the below which also list possible solutions for further improvements, through Minitab robustness measurement results for reduced changeover time to 49.3 minutes are obtained.

Table 5.3: Implementation of ECRS for Failure mode

Process	Failure mode	ECRS
Preparation	After machine stop,find change tools	E
Mold Exchange	Reciprocating take tools	S
	2 operators,1 is free for long	C&S
	Not familiar with SMED	C&R
Test/Calibration	Sudden machine failure	E
	Testing multiple times	E
Measurement	Waiting for test	R&S
	Inappropriate measurement	E&R

Table 5.4: After P-FMEA upon the process to list improve solutions

Action Recommended	Classify	Minitab robustness results
Listing BOM, early preparation upon it	×	
Equipped with tool box or cart	×	
Arrange actions properly	○	According to the SMED process, assign different changeover actions to 2 operators
Propose multi-functional tools	○	Possible to upgrade tools,such as ergonomic tools
Standardize operation process	×	
Training by instructor	×	
Equipped with professional light	×	
Overcome it	×	
Regular and plan to maintenance	×	
Improve tools type	○	Use transportation to improve tooling,such as swivel wheel cart
Using MAHR to verify position	○	Positioning upon MAHR table
Information disclosure	×	
Regular matain mmeasurement tools	×	

After upgrade normal tools to ergonomic tools as shown in chapter 3.3.1, also equipped with swivel wheel cart for tool transportation, it is possible to further reduce changeover time for 2.2 minutes. Thereby, under Lean Six Sigma improve phase and integrating with ergonomic conditions, the total changeover time reduction is 47.1 minutes which is achieved significant improvements compared to the initial 111.9 minutes.

5.3 Motor manufacturing-Lean Six Sigma DMAIC Control phase

The Lean Six Sigma DMAIC control phase is vital to the maintenance of motor SMED manufacturing process improvement results. In addition to standardizing and documenting the improvement process, it also requires the establishment of a long-term process control system to achieve continuous improvement.

Figure 5.2 shows the analysis of the production data of the motor factory in the first half of 2013. The points are arranged randomly and all within the bounds. The average value is 47.89 minutes. It can be determined that these conversion data records are under statistical control, and the conversion time is reduced. And to maintain stability, according to the later technological development and progress can be used as a further improvement.

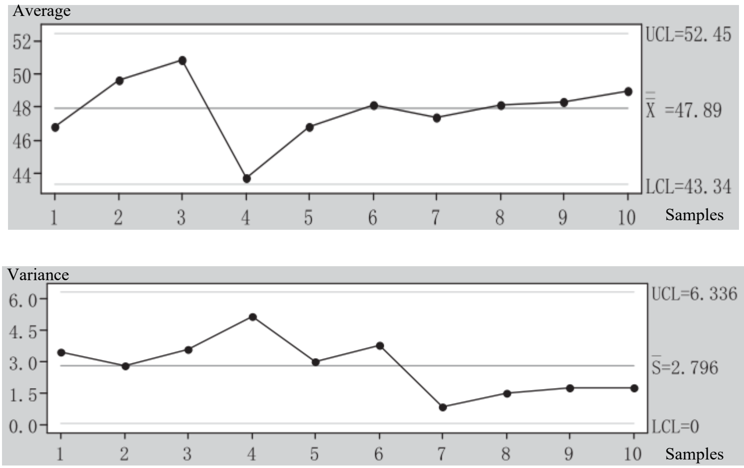


Figure 5.2: X-bar chart for AS head lathe changeover time

5.4 Case study results

The initial estimate CNC lathing motor AS time is 200 minutes, according to the average changeover time of the AS lathe before in using Lean Six Sigma improvement is 119.2 minutes and the theoretical average time of 49.3minutes after the improvement, but in considering integrate ergonomics conditions with Lean Six Sigma, the achieved total changeover time could be 47.1 minutes, it is concluded that the implementation of the motor manufacturing can reduce the changeover time by about 60.5%.

The implementation of Lean Six Sigma and integrate ergonomics conditions in motor SMED manufacturing can not only improve the production and operation of the enterprise and obtain financial benefits but from a long-term perspective, it can also improve the competitiveness of the enterprise at all levels.

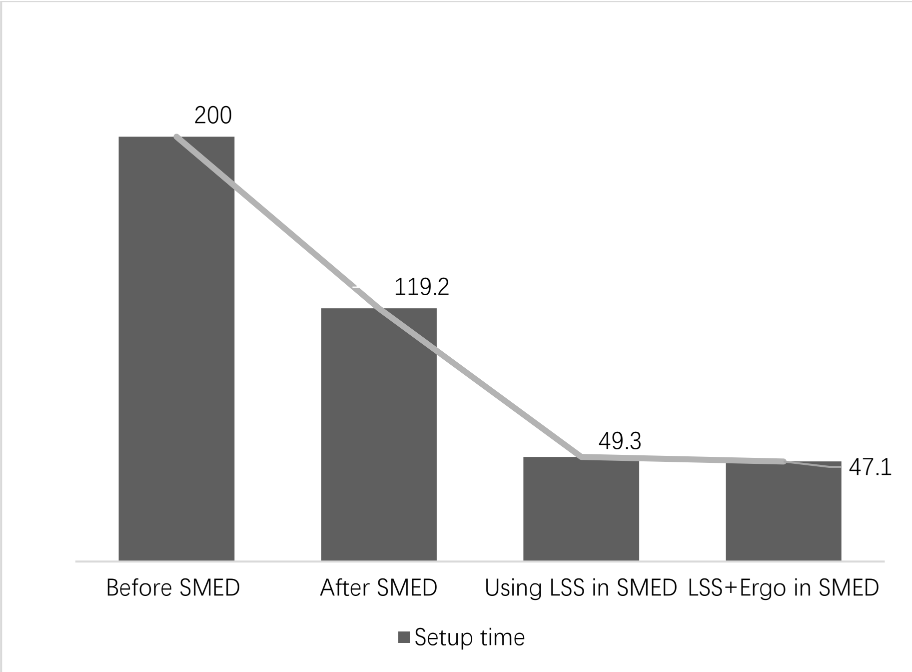


Figure 5.3: Summarize case study results

6. Conclusion

The article first briefly summarizes the development and implementation of lean manufacturing and its implementation, the combination of lean thinking and the theory of Six Sigma, and from this, proposes SMED methodology based on Lean Six Sigma, and finally, through the combination with ergonomic conditions, a deeper productivity improvement is carried out. Then for the combined analysis of the SMED method in DMAIC, the methodological phased analysis and the evaluation method of the SMED implementation effect are sequentially carried out. Finally, a case study for motor manufacturing in AS lathing of universal motor and brushless DC motor is used to evaluate the time reduction effect of the standard operation process of SMED, which can reach the theoretical expectation for 60.5% time reduction achievement.

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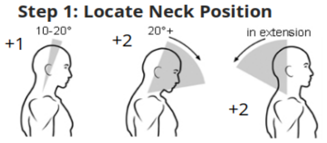
Annex

ERGONOMICS PLUS — REBA Employee Assessment Worksheet

Task Name: Date:

A. Neck, Trunk and Leg Analysis

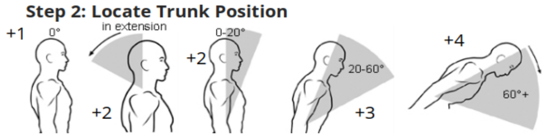
Step 1: Locate Neck Position



Neck Score

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

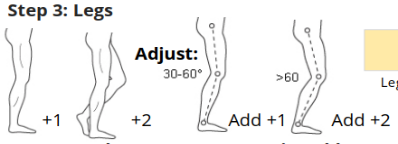
Step 2: Locate Trunk Position



Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs



Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A

+

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score

=

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

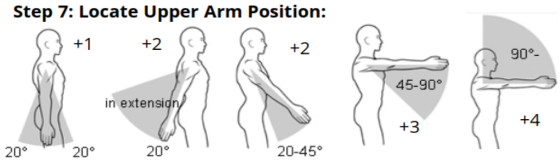
Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Score A	Table C											
	Score B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score = REBA Score

B. Arm and Wrist Analysis

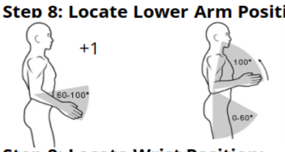
Step 7: Locate Upper Arm Position:



Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

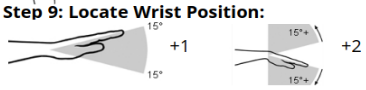
Upper Arm Score

Step 8: Locate Lower Arm Position:



Lower Arm Score

Step 9: Locate Wrist Position:



Wrist Score

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B

+

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***

Coupling Score

=

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base