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SMED Implementation for Setup Time Reduction: A Case Study in the Electronics Manufacturing Landscape

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ABSTRACT

In response to the pressing necessity for companies to enhance their product delivery efficiency, the reduction of setup time emerges as a crucial initiative. Setup, also known as changeover, often stands out as a time-consuming activity that adds no value to manufacturing operations. This paper aims to demonstrate the implementation of setup time reduction methods within a medium-sized manufacturing plant to diminish the overall process lead time. The project, centered on the application of Shigeo Shingo's Single Minute Exchange of Die (SMED) methodology for setup reduction, took place during a kaizen event. The systematic problem-solving approach, rooted in Deming's Plan-Do-Check-Act (PDCA) cycle, served as the foundation for generating and executing improvement ideas. An "idea assessment prioritization matrix" was developed to assess the viability of each idea. Consequently, the process setup time saw a significant reduction, decreasing from 80 to 43 minutes, with additional opportunities for improvement identified. The paper also explores the broader applicability of such techniques, not only in medium-sized plants but also in large-scale manufacturing industries engaged in mass production across various global locations.

Key words: Lean Manufacturing, Setup Reduction, Single Minute Exchange of Die (SMED)

INTRODUCTION

In the realm of contemporary manufacturing, the pursuit of operational excellence and heightened efficiency has become paramount for businesses striving to meet evolving market demands. One of the critical aspects influencing production efficiency is the duration required for setup or changeover activities, often identified as a major contributor to non-value-added time in manufacturing operations. This paper delves into the study and implementation of the Single Minute Exchange of Die (SMED) methodology within the context of a setup reduction initiative conducted through a Kaizen event. The landscape of manufacturing is dynamic, with companies facing an increasing need to deliver products more swiftly and adapt to rapidly changing market conditions. Setup time, the interval required to switch from producing one product to another, represents a crucial component in this pursuit of efficiency. However, it is frequently marred by time-consuming changeover processes, which, despite being essential, contribute little or no value to the product. Recognizing this, the focus of this study is on SMED, a methodology pioneered by Shigeo Shingo, renowned for its effectiveness in drastically reducing setup times. The true difficulty lies in the integration of reduced order and delivery sizes, especially in the context of just-in-time practices. With customers demanding swift delivery and high reliability, achieving short lead times in production emerges as the most effective strategy [7,8]. When dealing with intricate changeover procedures, the "inspiration of the moment" approach should be replaced by a "standardized setup method," meticulously developed by machine designers [9, 10, 11]. This shift is imperative for efficient and streamlined operations.

The overarching objective of this paper is to provide insights into the application of SMED methodology in a medium-sized manufacturing plant with the specific goal of reducing overall process lead time. The project unfolds within the framework of a Kaizen event, a methodology rooted in continuous improvement. Kaizen, meaning "change for better" in Japanese, aligns seamlessly with the ethos of enhancing processes incrementally over time. The SMED methodology, as a central pillar of Kaizen, becomes instrumental in achieving swift and effective changeovers, thereby minimizing downtime, and optimizing production flow. The implementation of SMED is not a standalone effort but rather a systematic approach deeply rooted in the Plan-Do-Check-Act (PDCA) cycle proposed by W. Edwards Deming. This scientific method serves as the foundation for problem-solving, allowing for the generation and implementation of improvement ideas in a structured manner. To prioritize these ideas, an "idea assessment prioritization matrix" is developed, ensuring a methodical evaluation of their feasibility and impact on setup time reduction. As the study unfolds, the paper not only explores the successful reduction of process setup time – a tangible outcome of the SMED application – but also identifies additional opportunities for improvement. Furthermore, it extends its purview to discuss how such methodologies can transcend the boundaries of a medium-sized plant and find application in larger manufacturing industries engaged in mass production across diverse global locations. Through a comprehensive examination of the SMED methodology in the context of setup reduction within a Kaizen event, this paper endeavors to contribute valuable insights to the broader discourse on operational efficiency in contemporary manufacturing settings. Several notable transformations in setup reduction have reshaped the operational landscape of manufacturing companies, giving rise to significant trends. These trends include an upsurge in product variety, an enhancement in product quality, a reduction in product lifecycle duration, and shorter lead times. The pace of these changes has accelerated, driven by escalating customer expectations for heightened product functionality and quality, influenced by an increasingly consumer-oriented society. To maintain competitiveness in the modern market, companies must not only diversify their product offerings but also exhibit the flexibility to swiftly adapt to market dynamics. The traditional mass production system model, conceptualized by Ford, relied on large lot sizes, and extended production runs. However, this paradigm is undergoing a shift toward a new production approach characterized by smaller lot sizes. Producing smaller quantities enables companies to align their production more easily with current demand, eliminating the need for prolonged production runs before transitioning to the next task. This shift results in substantially reduced total production lead times, sometimes spanning only a few days or even hours. Apart from enhancing production flexibility and shortening lead times, the adoption of smaller lot sizes offers additional advantages. Mustaquim (2024) uses remote sensing method in land surface which will used for manufacturing and diminishing nonvalue added time tracking system [27]. Companies can streamline their inventory levels by producing precisely what customers require, promptly shipping goods after production. This not only minimizes storage costs by reducing the reliance on warehousing but also lowers handling, transportation, and obsolescence expenses. High inventory levels correlate with slower turnover, posing a greater risk of obsolescence and increased likelihood of damages during storage and handling, leading to potential scraps or rework. Smaller lot sizes contribute to a higher product assortment and improved quality, along with shorter delivery times, culminating in increased customer satisfaction. Additionally, by reducing costs, companies have the option to deliver greater value to customers through lower prices, heightened satisfaction, and an expanded market share. However, it's essential to note that frequent setups accompany smaller lot sizes. Consequently, an operation with extended setup times, spanning several hours, may face challenges in adopting a small lot size approach, as the time allocated to setup activities could offset the benefits of the approach itself.

SETUP REDUCTION IN LEAN MANUFACTURING:

Lean manufacturing stands as both a philosophy and a set of practices committed to the eradication of waste and variability across all business processes. In this context, waste is defined as anything that adds cost without providing value from the perspective of the end customer. Widely embraced on a global scale, lean manufacturing has become one of the most prevalent and adopted production philosophies. The success and widespread adoption of lean manufacturing can be attributed to influential publications, with two notable books playing a pivotal role: "The Machine That Changed the World" (Womack et al., 1990) and "Lean Thinking" (Womack and Jones, 1996) [1]. These seminal works not only define the principles of lean manufacturing but also introduce a range of tools and techniques integral to its implementation. A standout methodology within the realm of lean manufacturing tools is the Single Minute Exchange of Die (SMED). This systematic approach is designed to methodically reduce the setup time of operations, aiming to transform it from a lengthy process spanning hours to a more efficient timeframe of minutes. SMED, as part of the lean manufacturing toolkit, contributes to the overarching goal of enhancing operational efficiency by minimizing non-value-added time, aligning with the core tenets of lean philosophy. Rahman et. al (2023) considers the cryptocurrency system which is the most important factor for electronics sector for choosing mapping and materials for smooth production [17,30]. Fayshal et. al (2023) considers the environmental factors and safety risk assessment factor for the human and environment and this study has significantly depended on these factors [25,32]. Kamal et. al (2019) describes evidence by using RFID technology for warehouse management by android application which has great impact on worker motivation to work in an electronics industry that reduce the non-value-added time [12]. Parvez et. al (2022) gives a Great discussion on ergonomics factor of students from which we consider the human working posture for the efficiency measurement of worker in the electronics plant because ergonomics factors are one of the most crucial matters for the productivity improvement changeover time for the SKU is important to reduce the lead time [13,14]. Ullah et al. (2023) & (2024) describes very gently in his three different papers regarding manufacturing excellence, scheduling operation and equipment efficiency from which we can consider for the overall equipment selections and job shop scheduling purpose that has great impact for industrial non-value adding time dismissing. They also consider the value stream mapping concept for increased profit through less wastage [20,22,24,30]. Shakil et. al (2013) interprets the process flow chart for a jute mill which is very informative for our industry data and SMED Production value added time minimization research [21]. Hossain et al. (2023) and Hasan et al. (2017) also discusses the electricity generation from moving vehicles that can be used for machine continuation of a factory when we have done my research and gone for using single minutes of our production [16,33]. Molla et al. (2023) describes the importance of medical textiles which have both plant able and implantable options that will our future research target [31].

TRADITIONAL APPROACHES TO SETUP REDUCTION

Historically, addressing the challenge of setup reduction involved two primary approaches. The first centered on enhancing the skills of operators in executing setup operations, but this method proved to be ineffective. The second approach involved consolidating production for various small orders to distribute setup times across larger lots. However, this approach resulted in overproduction and surplus inventory, as companies had to accumulate a larger inventory to meet extended time periods. To mitigate the costs associated with excess inventory and material handling, a third strategy emerged, known as the economic lot size strategy. is used. Companies would produce at the optimal lot size, determined as a trade-off between changeover and inventory carrying costs. The SMED technique has proved to be effective at dramatically reducing setup times. Rahman (2015) interpret how supplier selection may affect the Electronics sectors for an industry that plays significant role for Lean Production Management and cost minimization when we go for SMED, and data driven environment [11]. Rahman and colleagues (2023) applied a machine learning algorithm in their research, particularly focusing on predicting the performance of the production operations sector, especially in scenarios involving substantial amounts of big data. This study is deemed highly beneficial, laying a foundation for potential expansions in future research endeavors. In upcoming investigations, the plan is to incorporate extensive datasets, leveraging the insights gained from this research to contribute to the broader scope of knowledge and understanding [18,19]. Molla et al. (2024) describes in a significant way regarding the covid data in the United States and global side from which we can follow the covid protocol and use this for maintain rules and regulation in the production floor [23]. Noman at el. (2020) done a good project on data retrieval approach and we will consider as we have a future for in the future [28,29].

SINGLE MINUTE EXCHANGE OF DIE (SMED) METHODOLOGY

The origins of SMED technique can be dated back to 1950, when Shigeo Shingo [6], then management consultant at the Japan Management Association, was asked to eliminate bottlenecks created by three large body-molding presses at Toyo Kogyo’s Mazda plant in Hiroshima (JMAC). During this survey Shingo had the first of a series of breakthroughs that would later become famous under the name of SMED. By observing an 800-ton press setup, Shingo realized that "there are two types of setup operation: • Internal setup – setup operations that can be performed only when the machine is stopped, such as mounting and removing dies. • External setup – setup operations that can be completed while the machine is running, such as transporting dies to or from storage" (Shingo 1989) [6]. He observed that by performing operations such as organizing and preparing the bolts externally, it was possible to reduce the setup time by 50 percent. In 1957, Shingo was investigating the operation of machining diesel engine beds at the Mitsubishi Heavy Industries shipyard in Japan. He proposed to modify the marking-off procedure so that the dimensioning and centering of the engine bed would occur in a second planar table rather than on the original table. By doing the work in advance of needs, all that was left to be done when the changeover occurred was to swap the new table with the previous one. This measure increased productivity of the planning operation by 40 percent and represented the first successful attempt to convert an internal setup operation to external. The insights gained by Shingo up to that moment were consolidated thirteen years later at Toyota Motor's Honsha plant. Based on Shingo's suggestions and the application of the principles of distinguishing internal and external setup operations, converting internal to external, and improving operations in both categories, Toyota was able to reduce their 1000-ton Scheoler press setup time from four-hour to three minutes. Expecting to find that any setup could be performed in less than ten minutes and having the methodology first been tested in press shop floors, Shingo named his concept "single-minute exchange of dies" or SMED (Shingo 1989) [2].

RESEARCH OBJECTIVE:

A process is defined as a sequence of activities or procedures wherein raw materials, or pre-machined parts/components undergo further processing to yield a finalized product. To enhance production, a process capability study is undertaken for new or modified production processes. This study aims to optimize production performance by assessing total variability and ensuring process stability. In the quest for process improvement, it is often necessary to compare the output of a stable process with defined specifications, evaluating how well the process aligns with these specifications. This research focuses on utilizing PCA (Process Capability Analysis) to analyze the variance of quality characteristics, specifically the air hole boring axis referred to as "205 eksen." The objective is to explore the relationship between SMED (Single-Minute Exchange of Die) implementation and equipment-to-apparatus design. PCA in this study is directed towards both operators and processes, providing insights into the functional parameters of the product. Through this approach, the process capability study becomes a tool for measuring and understanding the functional aspects of the product.

METHODOLOGY FOR SMED IMPLEMENTATION

Shigeo Shingo built the foundations for SMED implementation. He recognizes eight techniques for implementing SMED (Shingo 1985) [3]:

1. Separate internal from external setup operations.
2. Convert internal to external setup.
3. Standardize function, not shape
4. Use functional clamps or eliminate fasteners altogether
5. Use intermediate jigs
6. Adopt parallel operations.
7. Eliminate adjustments.
8. 8.Mechanization.

He also suggests that these techniques be implemented in a progressive, three stage approach (Figure 1).

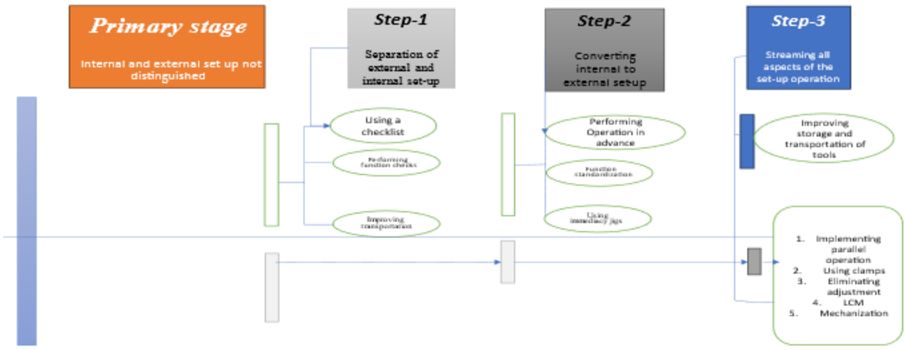

Figure 1: Theoretical steps and Procedure practices

Stage 1: To initiate the process of reducing setup time, the initial step involves the identification and differentiation of internal and external setup activities. Figure 1 illustrates that internal and external tasks are often indistinguishable, being carried out by the operator in a haphazard manner. Experience indicates that many tasks, which could be easily conducted externally, are frequently performed internally. For instance, preparing materials and tools for the upcoming job can be executed before the machine is halted, even while the previous job is still in progress. Similarly, the repositioning of tools and components can occur after the setup is finished and while the new job is underway. The separation of these tasks and their external execution, rather than internal, has the potential to reduce setup time significantly, ranging from 30 to 50 percent (The Productivity Press Development Team 1996).[4].

Stage 2: Transforming internal setup activities into external ones involves reconsidering the setup process as if it were happening for the first time and critically assessing the actual function and purpose of each operation. This conversion can be achieved through advanced preparation of operating conditions, standardization of functions, and the utilization of intermediary jigs.

Stage 3: Optimize every aspect of setup operations, encompassing both internal and external processes. Enhancements in external setup operations can be achieved by reassessing the storage and transportation of parts and tools. Implementing 5S activities proves beneficial in restructuring tool storage for easier accessibility by operators. Additionally, a constant check on tool conditions is essential to minimize disruptions caused by repairs or job rescheduling. For internal setup streamlining, consider introducing parallel operations or eliminating unnecessary adjustments. In traditional setups, adjustments can contribute to as much as 50% of the overall setup time, presenting a significant opportunity for cost savings (The Productivity Press Development Team 1996) [4]. Lastly, before considering mechanization, thoroughly analyze other techniques to ensure the most effective approach.

LEAN TOOLS FOR SETUP REDUCTION

In addition to SMED, the field of industrial engineering literature has introduced other tools applicable to companies seeking to minimize their process setup times. These tools have a broader applicability beyond setup time reduction and are applicable to any organization aiming to enhance its processes. Kaizen, integral to the philosophy of continuous improvement in lean manufacturing, constitutes one such tool. The term "Kaizen" is Japanese, combining "Kai" (to take apart) and "Zen" (to make good), representing a gradual approach in which lean manufacturing endeavors to enhance all business processes within an organization. Operationally, kaizen is defined as a "short-term intensive effort to dramatically improve the performance of a limited scope process" (Laraia et al. 1999) [5], employing a rapid, team-based problem-solving approach. Due to its format, kaizen is often selected by firms for implementing setup reduction initiatives. In the realm of problem-solving within lean manufacturing, standardization is a crucial principle. Tahiichi Ohno, the pioneer of the Toyota Production System, emphasized, "Where there is no standard there can be no kaizen." Standardization provides the basis for comparing pre-kaizen and post-kaizen scenarios, determining improvements and their extent. Standards are fundamental for employee training and audits. Particularly in setup reduction efforts, standardization is vital as it often involves defining new procedures for setup operations. Standardization is positioned at the end of a well-defined process, aligning with Deming's PDCA (Plan-Do-Check-Act) cycle for process improvement (Figure 2). Deming's cycle forms the basis of a scientific approach to problem-solving, asserting that improvements require a systematic identification of root causes (Plan). Effective countermeasures are then developed only after analyzing and unveiling root causes (Do). Corrective actions are initially implemented on a small scale, with results assessed by comparing new and old scenarios. A gap analysis is performed between actual and expected scenarios (Check). Only after proving effectiveness are corrective actions implemented on a large scale using new, standardized operating procedures (Act). This approach ensures that problems are addressed at their root, preventing future recurrences.

Figure 2: Standardization and PDCA

Another valuable tool in the realm of lean manufacturing, frequently advantageous in setup reduction, is 5S. This operational approach is designed to establish a clean, organized, safe, and productive workplace. The term "5S" is derived from the five Japanese words representing continuous improvement: Seri (Sort), Seiton (Set in order), Seiso (Shine), Seiketsu (Standardize), and Shitsuki (Sustain). 5S proves beneficial in setup reduction initiatives in several ways. The removal of dirt and dust contributes to better equipment maintenance and creates an environment where machine malfunctions are easier to detect, ultimately preventing breakdowns—a common cause of prolonged setups. Moreover, more reliable equipment reduces the likelihood of producing defective products, leading to shorter first-piece quality inspections. Safety is also enhanced through increased detection of abnormalities and hazards, while the elimination of unnecessary tools contributes to maintaining a risk-free environment. Ultimately, a cleaner workplace boosts morale, often translating into increased work productivity.

HIGH VOLUME, LOW MARGIN MANUFACTURING

Historically, SMED techniques have found application in sectors where "lean" methodologies are implemented to enhance profit margins, facilitate cost reductions, or prevent the outsourcing of manufacturing to low-cost labor markets. Industries characterized by high-volume production of low-margin products, such as consumer electronics, have also utilized SMED. Devices like mobile phones, MP3 players, tablet computers, and readers fall into this category. In these industries, the following aspects of SMED implementation are particularly relevant:

Separation of internal and external operations: For instance, the changing of large multi-cavity injection molding tools for cell phones, which previously took up to four hours, can now benefit from separating mold heating and fixturing operations, reducing downtime.

Conversion of internal to external processes: Processes like heating the mold to achieve uniform and proper molding temperature, which used to take several hours within the press, have been transformed into more efficient external operations.

Standardization of function, not shape: Innovative mold design concepts, like plate molds, have emerged to accommodate lean manufacturing. These molds feature thin removable plates with shapes for individual plastic parts, facilitating easier movement in and out of the press for part removal.

Use of functional clamps or elimination of clamping: Lean principles have simplified clamping of molding tools onto press plates. Modern clamps designed with self-locating and floating catch bars secure molds in a few imprecise positions, departing from the rigid angle iron structures of the past.

Adoption of parallel operations: In the consumer electronics sector, where numerous parts need molding, loading inserts into mold cavities was traditionally done manually. Vision systems now enable this loading operation outside the press, with automatic verification before loading into the mold, further confirmed by intelligent agent vision systems.

Mechanization: Lean manufacturing principles have deeply influenced the plastics injection molding field. Automatic mold changers have been developed to bring high levels of automation and productivity to high-volume, small-lot manufacturing operations. These systems are particularly valuable in industries like consumer electronics, where multiple mold changes are necessary to manage inventory costs and align production schedules with the fluctuating demand cycles. Mechanized tables and robotic carts complement these automatic mold changers, providing a safe and compact configuration for various plastic molding tools.

FORMULATION OF SMED STEPS

Drawing on the principles of Shigeo Shingo, the scientific approach of the PDCA process to problem-solving, and the concept of kaizen, a comprehensive method has been developed as a reference for any company engaging in setup reduction kaizen. A notable case study by Souke (1999) presented a predictive model for setup reduction, serving as a valuable reference for future applications [6]. The method outlined in this paper integrates a general setup reduction model into kaizen, acknowledging the constraints of time and resources.

IDENTIFY THE NEED FOR SETUP REDUCTION:

Before initiating a setup reduction kaizen, it is imperative to identify the need for reducing setup times. The goal should not be merely reducing setup time to an arbitrarily chosen duration; instead, it should align with a broader objective, such as addressing a capacity bottleneck or resource shortage. This focus ensures project alignment and commitment.

DEFINE SETUP TIME:

Setup time, also known as changeover time, is defined as the duration from completing the last good part of one lot to completing the first good part in the next lot. Unlike the traditional notion that focused solely on tooling attachment and detachment, actual changeover time encompasses all activities required to prepare the machine for producing the new lot. It is crucial to include the time spent producing the first part of the new lot, often performed in manual mode with longer cycle times.

DATA COLLECTION AND ANALYSIS:

Various approaches can be employed to study the setup process. Using a stopwatch provides a reasonable estimate of setup times, while being on the shop floor offers insights difficult to capture from a secondary view. Video filming, reviewed with the kaizen team, allows for a thorough analysis of each setup activity. Operators, likely members of the kaizen team, can describe their actions and reasoning, enabling group discussion. Spaghetti charts and setup observation analysis worksheets, utilizing the "FAST" categories (Foresight, Attachment, Setting, Trial runs), aid in documenting activities and times for analysis.

FAST CATEGORIES:

F - Foresight or preparation step A - Attachment or mounting/dismounting Step S - Setting, centering, dimensioning T - Trial runs and adjustments. The significance of each category is reflected in typical percentages of total time, as shown in Table 1 (Shingo 1989) [3].

Table 1: Basic Setup Steps before SMED Improvements

Step	Percentage of Setup Time
Preparatory Measures, Post-process Adjustments, Verification of Materials and Tools	35%
Attaching and Detaching Blades, Tools, and Components	10%
Dimensions, Configurations, and Adjustments	10%
Testing Iterations and Fine-Tuning	45%

BRAINSTORMING (STAGES 1, 2, 3 OF SMED)

When Shigeo Shingo introduced the Single-Minute Exchange of Die (SMED) methodology, he pioneered a shift from individual problem-solving to a team-based approach in kaizen. Unlike the initial scenario where Shingo worked independently, kaizen involves the entire team in generating ideas to enhance setup operations. The process begins with a thorough evaluation of the current state, followed by the implementation of SMED. Initially, the team distinguishes setup activities into internal and external components. Activities mistakenly considered internal are transitioned to the external category. Subsequently, the team reviews the entire setup sequence to identify internal steps that can be converted into external ones. A comprehensive brainstorming session ensues, aimed at proposing solutions to streamline both internal and external operations. The ultimate objective is to establish a "standard operating procedure" (SOP) for setup activities. It is crucial to emphasize that standardization is the linchpin for ensuring sustained and effective improvements over time.

IDEA PRIORITIZATION AND IDEA ASSESSMENT MATRIX

The concept underlying an assessment matrix stems from the recognition that in any selection process, various factors come into play, each carrying distinct importance in the decision-making process. Evaluating competing elements can be challenging without dissecting the influence of each contributing factor objectively. The use of a weighted matrix serves the purpose of identifying and appraising these factors, leading to a more informed and rational decision. In this context, the goal is not necessarily to pinpoint a singular, optimal solution, but rather to systematically evaluate the effectiveness of each idea in enhancing setup operations. To facilitate the setup reduction assessment process, five specific criteria have been delineated and are outlined in Table 2. This approach ensures a comprehensive and nuanced evaluation, contributing to a more thorough and reasoned solution for improvement in setup operations.

Table 2: List of Factors for Idea Assessment Matrix

Measure	Dimension of Evaluation
Viability	Can the concept be practically put into action?
Effect	What extent of influence will the concept have on reducing setup time?
Accessibility	How straightforward is the implementation of the concept?
Security	What level of safety does the suggested approach ensure?
Price	What is the cost associated with implementing the suggested concept?

To account for the relative importance of each criterion, weights from 0 to 10 (with a 5-point interval) are assigned. It is important to note that weights should be assigned by management, as they come to reflect the strategic outlook of the company in determining, for instance, whether priority should be given to cost rather than ease of implementation. The team ranks each idea with a value ranging from 0 to 5 on each decisional criterion, and a total score is calculated as follows:

Idea Total Score = Σ criteria (weight * score) (1)

Ideas with higher scores should be implemented first, as they represent the most feasible, fastest, and least costly consuming solutions.

IDEA IMPLEMENTATION

A preliminary standard operation procedure (SOP) is defined based on initial improvement suggestions. The idea is to validate the effectiveness of the new procedure as new ways to reduce setup are discovered and practiced. A plan is then created for the kaizen follow-up which comprises the following:

- Training plan. Training is a key element for the success of set-up reduction efforts. Operators should be educated on quick changeover and be informed of the reasons they are being scrutinized. A common pitfall is that the operator perceives the setup monitoring as an individual performance assessment tool rather than an overall improvement process. The result is that, when observed, he/she gets nervous and begins following different procedures and operating at a different pace than usual, thus producing unreliable and biased data.
- Communication plan. The team must communicate the changes to all employees directly or indirectly affected to make sure they are aware of the new procedures. A communication plan is especially important in case of a first setup reduction project, as it communicates leadership support and the need for change.
- Implementation plan. An action plan is defined to link the ideas selected to the actions required to implement them. The plan should define the who, what, when where and how for implementing the solution and be constantly reviewed and updated. Weekly meetings can be scheduled to track results against the initial goals and to discuss unforeseen problems as they arise. A meeting after completion of the follow-up phase allows the team to evaluate the effectiveness of the actions taken and define further corrective measures to address issues still unsolved.

IDEA VALIDATION, ADJUSTMENTS AND STANDARDIZATION

As per PDCA methodology, improvement of setup operations is an ongoing process made of continuous little adjustments rather than a one-shot event. By performing one or more turns in the PDCA cycle, one can improve its plan and/or develop contingency plans to address unforeseen circumstances. As implementation efforts take place, the SOP is periodically reviewed until the final standard work is eventually defined. It is important that the standard work instructions be documented and made visible to all in the working area. The team must develop and complete training for all operators who will be performing the new setup to make them familiar with the new procedure. Enforcement of new measures is also important to make the new procedure become a habit. Audit sessions should be scheduled to periodically analyze results and keep track of improvements. Ullah et al. (2024) uses value stream mapping with a good mathematical process that is useful for this research specifically when we must do much for reducing wastage and nonvalue adding time in the production floor [15].

IMPLEMENTATION

The method explained above was applied to a mid- sized manufacturing facility that produces track roller bearing systems for use in military and commercial aviation industry. In particular, the project focused on reducing setup times in a CNC turning center dedicated to outer races production. The outer race production process takes place in two distinct sequences. During the first sequence, the part is held by the main spindle on the left side of the turret while tools shape the OD (outer diameter) and ID (inner diameter). The part is then cut off from the original bar of material and work shift takes place, where a secondary spindle (sub-spindle) moves close to first spindle and the part is transferred on the right side of the turret. The problem in the track roller production process was that of long lead times. 20 days are usually required to fulfill the customer's order whereas the lead time demanded by customer is five days for the same process. Also, due to inner and outer different cycle times, outer production was falling behind schedule, causing excess inventory of inner parts, which were waiting for their pairs before they could eventually be moved forward in the process as an assemble kit. Reducing setup would allow the company to avoid the bottleneck problem at the CNC turning center, while shortening the overall production lead time and lowering the amount of work in process inventory. The setup reduction effort was carried out with a kaizen format. A team was assembled, which comprised of the following:

- # Two machine operators.
- # Two supervisors (day and night shifts)
- # Two manufacturing engineers
- One continuous improvement leader (team leader)
- One external kaizen facilitator. The first part of the kaizen was dedicated to the as-is analysis. A setup process was videotaped, which allowed the team members to analyze the steps performed by the operator, his movements, and the time for each step. Also, a spaghetti chart was drawn, where distances travelled by the operator were recorded. With the help of the machine operator, activities were listed and the "setup observation analysis worksheet" compiled (Table 3). For each activity, time, and setup activity (defined as either internal or external) were recorded. Also, activities were classified into the "FAST" categories. As shown in the sheet, in the as-is state, most tasks were performed internally, adding up to a total setup time of 1 hour and 25 minutes. The second part of the kaizen was spent brainstorming ideas for setup process reduction. Activities were classified as internal or external, and those identified as external were taken out from the setup worksheet to create a separate kitting procedure. Kitting is the name used to identify the process of gathering and bringing all necessary tooling close to the machine before the actual setup begins and it is performed while the machine is still running the previous part. The following activities were externalized, for a total saving of 16 minutes:
- Obtain shop order and verify stock size
- Print out program hard copy from PC
- Obtain new tools and equipment (collets, jaws, spindle liner, inserts, boring bars, tool holders, drills)
- Setup gage blocks, plugs, etc.
- Put away new tools and equipment. To streamline internal activities, the possibility of reengineering the background edits was proposed, where the CNC program is loaded while the machine is still running the previous part rather than during actual setup. Additional ideas were brainstormed on how to improve the whole setup process, and each of them was linked to its corresponding setup step in the setup observation analysis worksheet. Ideas were then gathered and assessed by the team using the idea assessment matrix tool. Feasibility, impact, and safety factors were given a weight of 10 to account for their higher importance over cost and ease of implementation factors (Table 4). A standard setup operation procedure was defined, and a dry run for new standards was performed. A total of 24 minutes were saved from moving some activities from internal to external (17 minutes) and from work shift

modification (7 minutes). Ideas proposed were then reviewed and integrated with the new suggestion arose during the second setup observation. Many ideas involved tooling and area reorganization. For this reason, a 5S session was scheduled. The 5S activities helped in defining a more efficient way for equipment reordering and storage at point of use.

40 days after kaizen completion a follow up audit session was conducted. Results are shown in Table 5. The biggest improvement was achieved with externalizing kitting operations (17 minutes savings) and reengineering the work shift (7 minutes savings). Also, after the kaizen, the first video shows an additional 10-minute savings (setup time reduced to 50 minutes). The results can be further improved if the machinist is trained in standard work. The proper training in presetting operation would decrease jaw attachment operation by one quarter of the time (14 out of the 50 minutes was spent on jaw attachment). A second post-kaizen video reconfirmed this problem, as 10 out of 47 minutes were spent on jaw attachment and subsequent adjustments. The last shot, finally, shows a 50-minute setup, still with major delays in jaw attachment and work shift setting.

Table 3: Setup Study Evaluation Database

Mach.:	**KIASKT21LMS**		**Class Before**	**Element /Task Description**	**Time Before**	**Time After**	**Reftoidea**	**Class After**				**Category**			
Step#	Time		INT / EST												
	Cumulate.	Task													
1	0:01:00	0:01:00	I	Load database	0:01:00		1	internal	external	reduce	elimination	F	A	S	T
2	0:02:34	0:01:34	I	Take Lathe out	0:01:34			X							
3	0:03:01	0:00:27	I	Find new Lathe	0:00:27		2								
4	0:04:01	0:01:00	I	Install Lathe on turret	0:01:00		2,10	x							
5	0:06:21	0:02:20	I	Replace the inserts on boring bars (4)	0:02:20		12								
6	0:12:40	0:06:19	I	Change cut off/OD Inserts	0:06:19		12	X							
7	0:21:05	0:08:25	I	Take ID boring bars out and put on new b.b.	0:08:25			X							
8	0:27:36	0:06:31	I	Touch off all tools with probe	0:06:31		3	X							
9	0:28:22	0:00:46	I	Put tools away	0:00:46		11								
10	0:29:50	0:01:28	I	Collet change for main spindle	0:01:28		4	X							
11	0:32:05	0:02:15	I	Replace spindle liner	0:01:55		2	X							
12	0:38:05	0:06:00	I	Checked stock	0:07:00										
13	0:43:34	0:05:29	I	Load the stock and set the height of the bar feed	0:05:29		2								
14	0:43:34	0:02:25	I	Set ID instrument	0:01:38		6	X							

15	0:47:50	0:01:51	I	Establish the working schedule for the primary spindle at the zero position	0:01:49		X
16	0:52:32	0:04:42	E	Conduct a trial or practice operation of the primary spindle, following a single-block program, for example, in the first sequence	0:04:42		X
17	1:01:00	0:08:28	I	Replace the jaws on the secondary spindle.	0:09:32	7	X
18	1:05:09	0:04:09	I	Gliding mandibles	0:04:09	7	X
19	1:08:36	0:03:27	I	Adjust sub-spindle cutoff length to align with the main spindle.	0:03:31		X
20	1:13:00	0:04:24	I	Call up tools for sub spindle Zero (using shim)	0:04:24		X
21	1:18:23	0:05:23	E	Conduct a practice execution (using a single-block program example - II sequence) and make any necessary adjustments to that portion.	0:05:23		X
22	1:20:00	0:01:37	I	Verify the component (preliminary examination by the operator).	0:01:41		X

23	1:21:36	0:01:36	E	Allow the machine to execute the second segment.	0:0.9:40		X
24	1:25:30	0:03:54	I	Initial piece inspection (quality inspection)	0:03:44	7	X
		Totals			1:32:28		

Activity Categories			
F. Foresight	A. Attachment	S. Setting Conditions	T. Trial Runs & Adjustments
12% (10:55 min)	41% (35 min)	27% (23 min)	20% (17 min)

Table 4: Idea Assessment Matrix

	Criteria Weight Ideas	**10 Feasibility**	**10 Impact**	**5 Easiness**	**10 Safety**	**5 Cost**	**Total Score**
1	Apply editing to the backdrop	5	1	5	5	5	160
2	Have an expert dedicated to assembling kits for the entire facility.	3	5	3	5	2	155
3	Utility cart for temporarily setting aside tools while the machine is in operation.	4	2	5	5	4	155
4	Bring and ensure that the liners are clearly marked	5	4	5	4	5	180
5	Shift the machinery away from the inner machine to enhance operator mobility						N/A
6	Revise the zero-touch startup procedure and assess B-axis length for work shift optimization	5	1	5	5	5	160
7	Jaws specified by size range.	5	1	5	5	5	160
8	Prioritize external machinery during setup.						
9	tool holders require improved organization, preferably vertically with clear, easily readable labels						
10	Boring bar tool holder for tabletop use.	5	4	5	5	5	190
11	Collet holder rack	4	4	4	5	4	170
12	Restructuring Allen wrenches	5	4	5	5	5	190

CONCLUSIONS

This research is centered on the implementation of the Single Minute Exchange of Die (SMED) methodology to achieve a reduction in setup time within a manufacturing company. The findings of the study reveal a substantial decrease in setup time, showcasing the potential to cut down the initial 1 hour and 25 minutes to just 47 minutes. Moreover, by exploring modifications in the jaw attachment device (work holding device) and optimizing work shift arrangements, an additional time reduction of 17 minutes could be achieved. The successful implementation of lean manufacturing, being a cross-functional discipline, necessitates active participation from all divisions within the company. For the efficacy of standard work, enforcement emerges as a crucial factor, considering the inherent resistance to change among individuals. Periodic monitoring, as mandated by kaizen follow-up practices, serves as an incentive for machinists to adhere to the new standard procedures and familiarize themselves with the changes. In addition to championing lean initiatives, senior management plays a pivotal role in fostering a culture of change management and instilling a sense of shared responsibility and collaborative problem-solving. Throughout the research duration, it became evident that functions such as jaw attachment and CNC program updates significantly influence the company's kaizen goals.

This underscores the importance of labeling jaws and updating CNC programs. It is recommended that management develops a comprehensive training plan to familiarize operators with the new procedures and implements enforcement measures to ensure their consistent application.

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