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Optimizing Changeover Time of Lathe Production Line through SMED Techniques

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Abstract: The study focuses on the comprehensive optimization of the changeover process for a lathe production line using SMED (Single Minute Exchange of Dies) methodology tools. The study was conducted in a selected manufacturing company specializing in the production of bearings for the automotive industry. The study describes the affected production workplace, along with its current changeover state and subsequent evaluation, which reveals key inefficiencies, including long changeover times, non-standardized procedures, and frequent downtimes. The study then introduces improvements aimed at optimizing and reducing the changeover process. The recommendations include the development of standardized work procedures, enhanced operator training, improved material handling strategy, and the implementation of electric tools. The proposed potential changeover time savings exceed 30%, which translates into increased production capacity. Process optimization, including improved operational efficiency, is reflected in increased profitability. The benefits of this study are that it provides valuable insights for manufacturers utilizing lathe production lines who are striving to improve their operational practices and remain competitive in a dynamic market.

Keywords: Optimization, Changeover, Waste, SMED, Internal and External Activities.

Optymalizacja czasu przezbrajania linii produkcyjnej tokarek za pomocą technik SMED

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Streszczenie: Artykuł koncentruje się na kompleksowej optymalizacji procesu przezbrajania linii tokarskiej z wykorzystaniem narzędzi metody SMED (Single Minute Exchange of Dies). Badanie zostało przeprowadzone w wybranym przedsiębiorstwie produkcyjnym, specjalizującym się w produkcji łożysk dla przemysłu motoryzacyjnego. Artykuł opisuje omawiane stanowisko produkcyjne wraz z jego aktualnym stanem przezbrajania oraz kolejną oceną, która ujawnia kluczowe nieefektywności, w tym długi czas przezbrajania, niestandardowe procedury i dużą liczbę przestojów. Następnie badanie przedstawia ulepszenia mające na celu optymalizację i skrócenie procesu przezbrajania. Zalecenia obejmują opracowanie znormalizowanych procedur pracy, ulepszone szkolenie operatorów, poprawę strategii zarządzania materiałami oraz wdrożenie narzędzi elektrycznych. Proponowane potencjalne oszczędności czasu przezbrajania wynoszą ponad 30%, co przekłada się na zwiększoną zdolność produkcyjną. Optymalizacja

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procesów, w tym poprawa efektywności operacyjnej, znajduje odzwierciedlenie w zwiększonej rentowności. Korzyści płynące z tego badania dostarczają cennych informacji dla producentów wykorzystujących linie tokarskie, którzy dążą do ulepszenia swoich praktyk operacyjnych i utrzymania konkurencyjności na dynamicznym rynku.

Słowa kluczowe: Optymalizacja, Przezbrajanie, Marnotrawstwo, SMED, Czynności wewnętrzne i zewnętrzne.

1. Introduction

In today's rapidly evolving manufacturing environment, the need to increase efficiency and reduce operating costs is becoming increasingly important [1]. As manufacturing companies face growing competition and demand for high-quality products, optimizing production processes and maximizing their efficiency are becoming essential. One way to increase production capacity is by reducing the time required to adjust production machines from producing product type A to product type B [2][3]. This process is technically referred to as changeover. Excessive changeover times not only lead to increased operating costs but also reduce a company's ability to respond flexibly and efficiently to market demands.

Many studies have highlighted the importance of streamlining changeover processes. The SMED (Single Minute Exchange of Dies) methodology is widely recognized as an effective approach to reducing changeover times, allowing manufacturers to increase flexibility and efficiency. The goal of the SMED methodology is to perform as many changeover activities as possible while the machine is running, in order to save time and quickly transition from one product to another [4][5]. A large number of studies have documented successful SMED implementations across various industries, demonstrating significant time savings and cost reductions [6]. However, a gap remains in the literature regarding specific applications of SMED techniques on lathe production lines.

2. Structure of the production line Shinban L4

Based on the introductory section, which emphasized the importance of optimizing production processes to increase efficiency, the focus shifted to a detailed analysis of the lathe production line within the selected company. Specifically, the Shinban L4 lathe line was analyzed due to its long changeover time, representing a significant area for improvement. The layout and production flow of the Shinban L4 line can be observed in the following Figure 1.

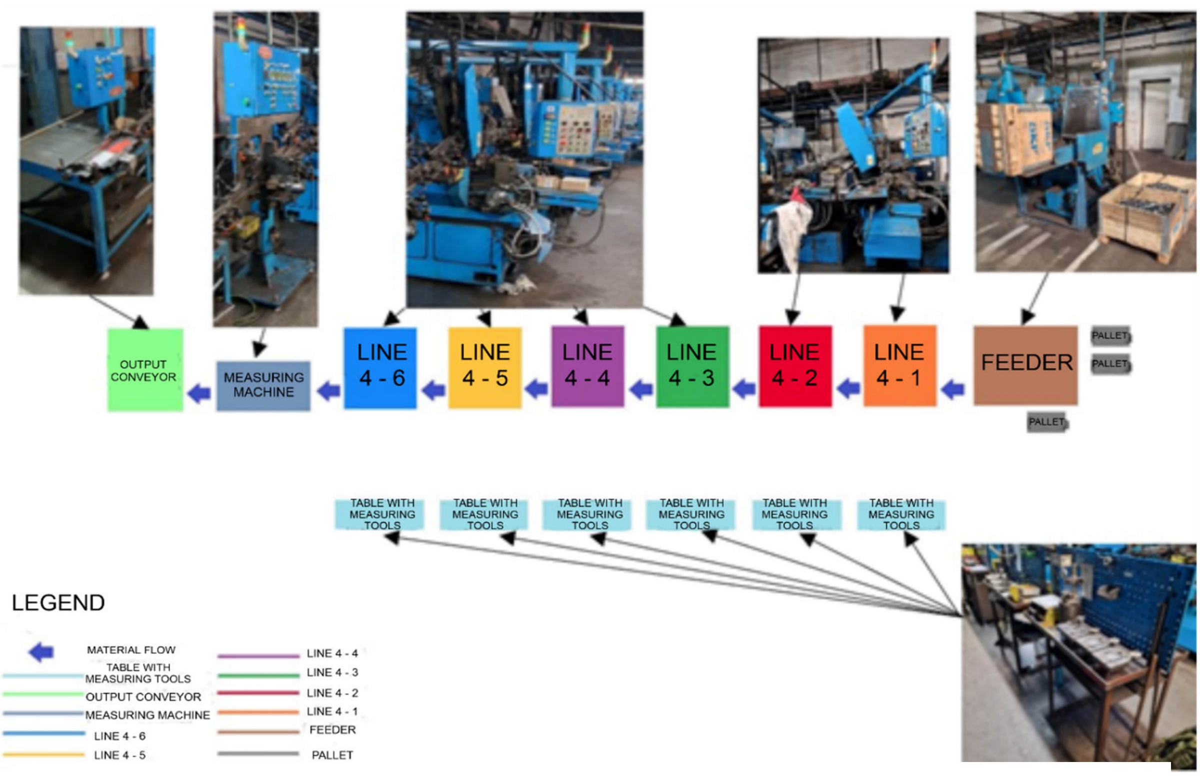

Figure 1. Layout and Material Flow of the Workplace Shinban L4. [Source: Authors]

The Shinban L4 workstation is a lathe line consisting of several key components. The first is the feeder, where pallets with rings designated for turning are placed. The rings are then transferred via a conveyor and chutes to the first lathe, with the supply being regulated by a series of sensors. The line consists of lathes Line 4 – 1 to Line 4 – 6, which are single-purpose machines that gradually process the rings. Between the individual lathes, the rings are moved by gravity, with each lathe performing a different part of the machining process. After turning, the rings are inspected by an automatic measuring machine, ensuring dimensional accuracy. Compliant rings continue down the line, while non-compliant ones are rejected. The inspected rings are then stored in the output bin, which arranges them in the correct position. The line is also equipped with auxiliary tables where tools and gauges are stored, and where control measurements are carried out during the setup of the line.

3. SMED Methodology

SMED (Single Minute Exchange of Die) is a systematic process focused on minimizing downtime, specifically the waiting (preparation) time between processing two consecutive different types of products or production batches. This method concentrates on reducing the time required for the reconfiguration of production equipment, such as changing dies in a press, reconfiguring a production line, or adjusting a machining tool. It is usually carried out by a team through organized workshops. The entire process is based on a thorough analysis of the reconfiguration process, which is typically conducted through direct observation at the workplace. Significant reductions in reconfiguration times from several hours to a few minutes are achieved by gradually eliminating waste from the process, reorganizing work during reconfiguration, standardizing procedures, training the team, utilizing special tools, and making technical modifications to machines [6].

3.1 Identification of Key Activities in the Shinban L4 Line Changeover Process

After the detailed description of the individual parts of the Shinban L4 lathe line, the setup process itself was also analyzed. Although the line as a whole operates efficiently, the changeover process represents a critical moment that significantly affects overall productivity. To collect the data needed for analyzing the initial state, five setup processes were observed and recorded. All measured values represent the average of these observations. These recordings allowed for a detailed examination of the setup process and identification of key deficiencies. Subsequent analysis of these recordings provided valuable insights into the inefficiencies impacting setup time and quality. In the initial analysis, it was identified that the average number of setups on the Shinban L4 line reaches a frequency of three cycles per month.

The changeover process of the Shinban L4 line includes several steps:

- preparation of tools and instruments at the tool dispensing station,
- setting of measuring tools intended for quality control of the turned rings,
- setting up the feeder that ensures the supply of rings for processing to the lathe,
- alignment of the lathes that form the basis of the line,
- setting of the measuring machine, which performs the final quality control,
- setting of the output conveyor, which is responsible for storing the turned rings in the correct position,
- inspection and testing, during which five sample pieces are produced and subsequently measured precisely.

The following Figure 2 illustrates the sequence of setup steps for the Shinban L4 lathe line.

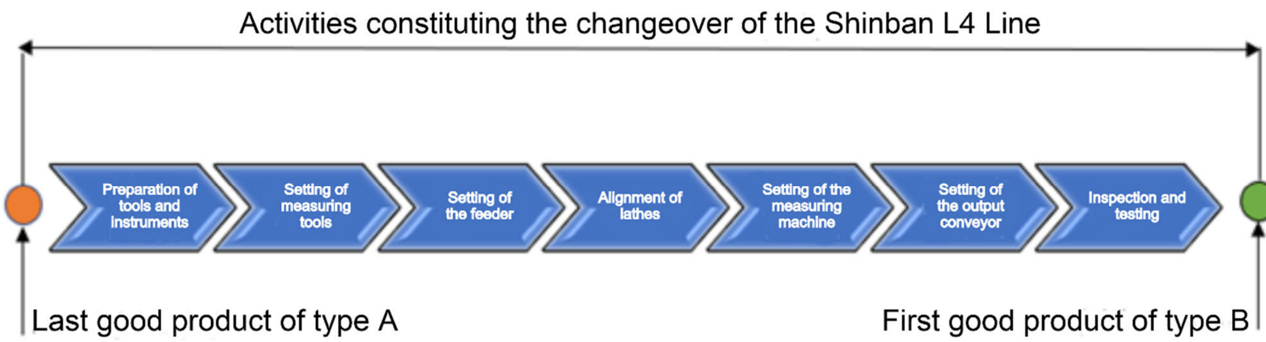

Figure 2 Activities constituting the changeover of the Shinban L4 Line [Source: Authors]

3.2 Determining the Duration of Individual Activities

In the analysis of the duration of individual activities, the measured values for each step of the changeover process serve to enhance understanding of the overall process efficiency and identify potential areas for improvement. The most time-consuming activity is the alignment of the lathes, which takes 11 hours and 55 minutes, accounting for approximately 82% of the total time. This phase also included lunch and dinner breaks, which are not counted in the overall time.

The setting of measuring tools took 1 hour and 2 minutes, representing 7% of the total time, while the preparation of tools and instruments required 36 minutes, making up 4%. Other steps, such as the setting of the feeder (18 minutes), inspection and testing (17 minutes), and the setting of the measuring machine (12 minutes), each accounted for roughly 2% of the total time. The shortest step was the setting of the output conveyor, which lasted 10 minutes and constituted about 1% of the total setup time.

Another finding was that the changeover process does not follow any standardized procedure, leading individual workers to utilize various methods and approaches during the changeover of the line. The percentage distribution of the times for each changeover step is illustrated in the following Figure 3.

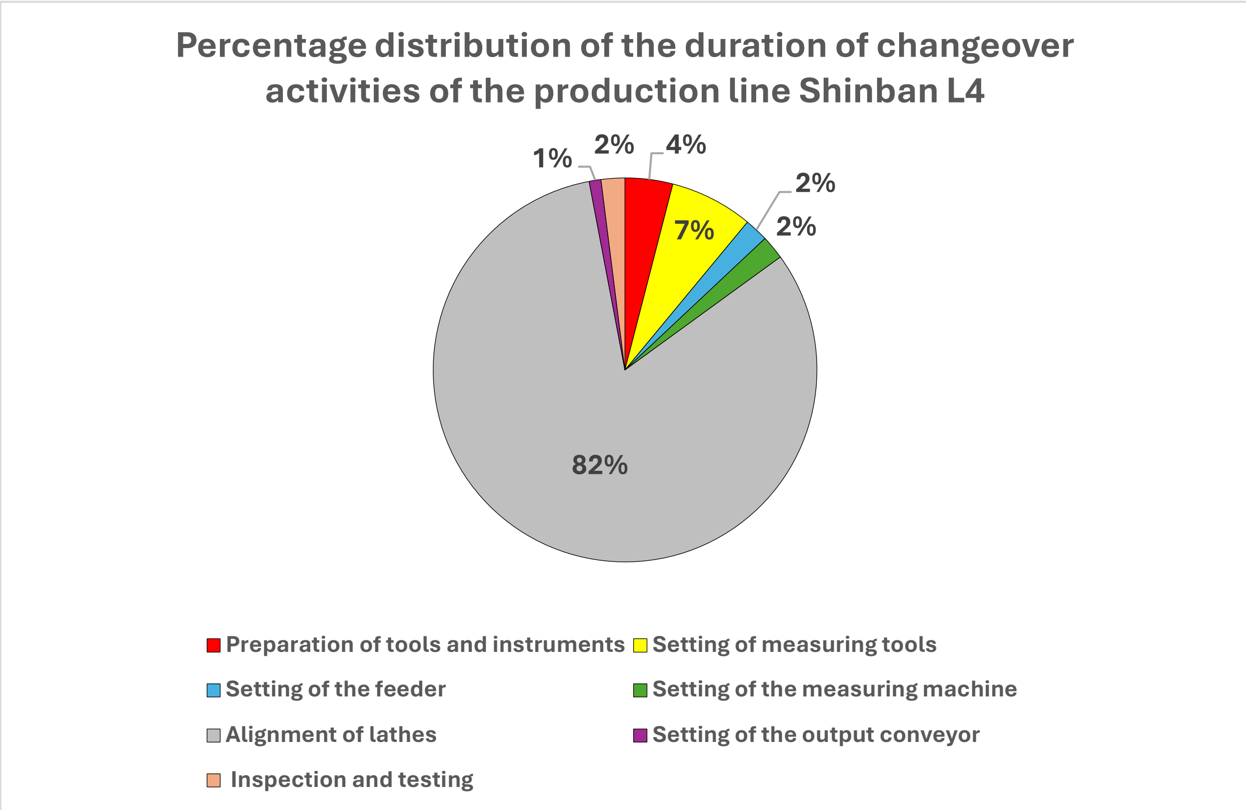

Figure 3 Percentage distribution of the duration of changeover activities of the production line Shinban L4 [Source: Authors]

Given that the alignment of the lathes accounts for up to 82% of the total duration of the changeover process for the line, this study places significant emphasis on optimizing this step. The duration of this step has a considerable impact on the overall efficiency and productivity of the line.

3.3 Categorization of Setup Activities into Three Categories

After a thorough analysis of the video recordings and data obtained from the changeover process of the Shinban L4 line, the activities were divided into three categories:

- Value-adding activities during the changeover,
- Non-value-adding activities during the changeover,
- Downtime.

Value-adding activities in the changeover process are those tasks that directly contribute to progress toward completing the changeover. Examples include adjusting the machine's chutes or changing tools. Ideally, all activities performed by the worker should fall into this category.

Non-value-adding activities are tasks that do not speed up the changeover process. Examples might include unnecessary movements, searching for tools, or other inefficient activities that do not increase productivity.

Downtime refers to periods when the worker is not engaged in any productive activity. In practice, this can involve leaving the workplace, watching a colleague work, or chatting with coworkers.

In the following Figure 4, individual activities are categorized according to their percentage representation in the changeover process. The chart indicates that value-adding activities (shown in blue) account for 50% of the total time, suggesting that half of the activities directly contribute to completing the setup. On the other hand, downtime represents 33% of the time (shown in red), highlighting room for improvement in process efficiency. This downtime indicates that a significant portion of working time is unutilized, indicating a need for optimization and the elimination of unproductive work aspects. Non-value-adding activities account for 17% of the total time (shown in orange). While this is a smaller proportion, their presence still suggests areas for improvement by reducing unnecessary movements and other inefficient activities. These findings are crucial for optimizing the changeover process and increasing overall productivity.

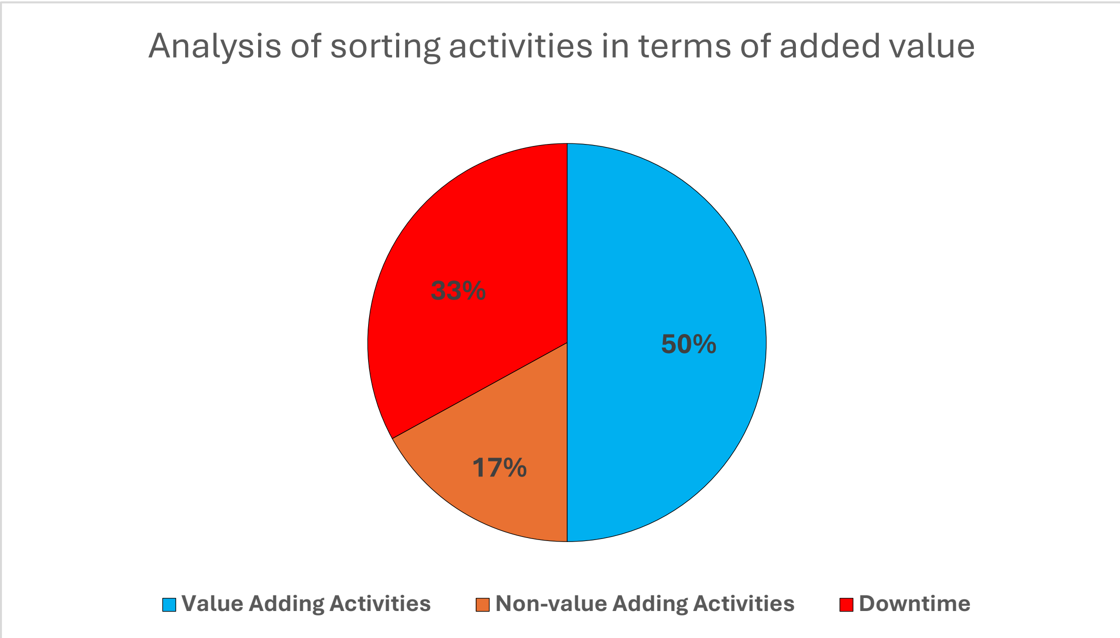

Figure 4 Analysis of sorting activities in terms of added value [Source: Authors]

3.4 Summary of Identified Deficiencies

Through measurement and observation of the changeover process of the Shinban L4 lathe line, the following deficiencies were identified:

- the absence of a standardized setup procedure,
- absence of distinction between internal and external setup activities,
- a high number of downtimes,
- overloading of the setup operator, who performs multiple tasks simultaneously,
- inappropriate placement of spare screws,
- the exclusive use of traditional tools,
- each employee uses their own tools,
- the overall time required for setup is excessively long.

3.5 Identification of internal and external activities of the Shinban L4 line changeover process

In the changeover process, there were no external activities, meaning that all activities performed by the changeover worker were classified as internal. This indicates that the entire changeover occurred only after the Shinban L4 production line was shut down. This fact is crucial as it suggests that all activities were conducted within the process while the line was inactive. This aspect of the setup process can be clearly observed in the following Figure 5.

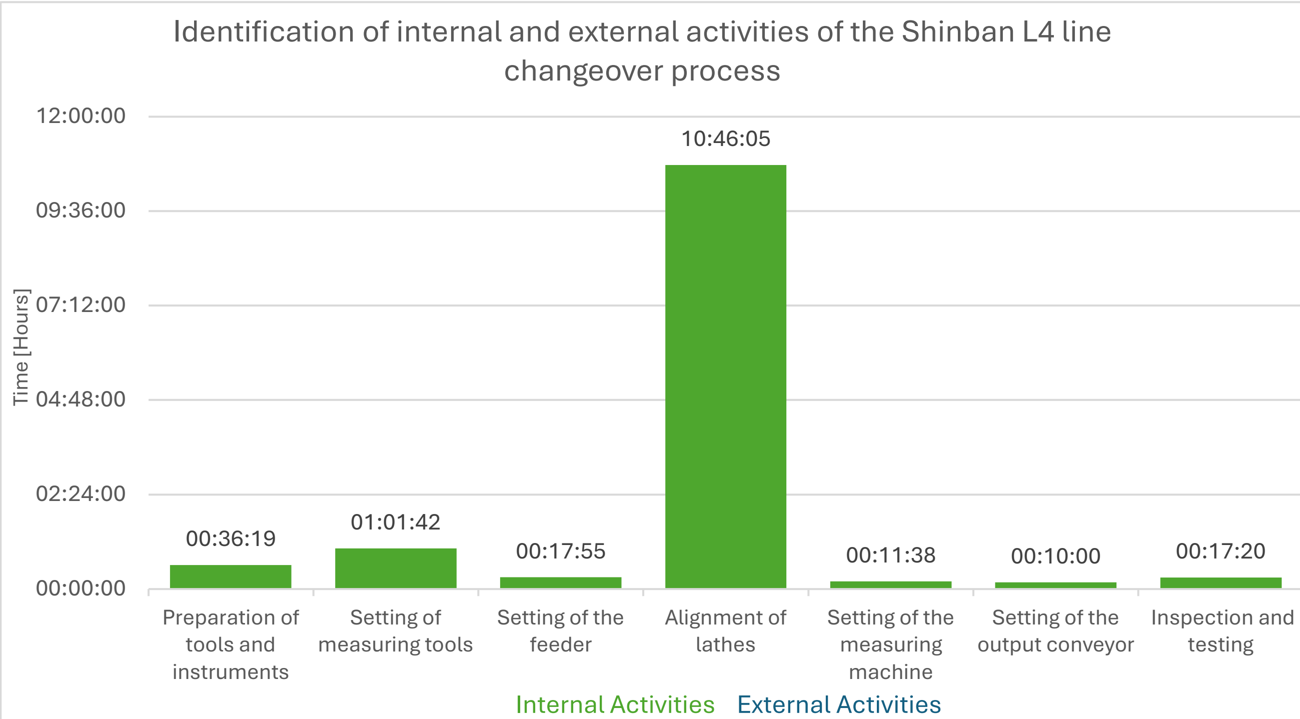

Figure 5 Identification of internal and external activities of the Shinban L4 line changeover process

[Source: Authors]

3.6 Transformation of Internal Activities to External

After conducting the analysis, internal activities were identified that could be transformed into external ones. These activities include:

- preparation of tools and instruments,
- calibration of measuring devices.

All activities related to the preparation of tools and instruments could be transformed into external ones. The changeover worker can prepare tools and instruments even while the Shinban L4 line is running. This change did not require any additional costs and could help save up to 36 minutes and 19 seconds. Similarly, activities associated with the calibration of measuring devices could also be converted to external. This change could potentially save 1 hour, 1 minute, and 42 seconds from the total setup time. Calibration of measuring devices during the operation of the line could be carried out directly at the workplace tables.

Further transformation of other activities to external was not possible, as all other tasks required the line to be shut down. The following Figure 6 shows the distribution of activities in the different sections of the setup process after the adjustments.

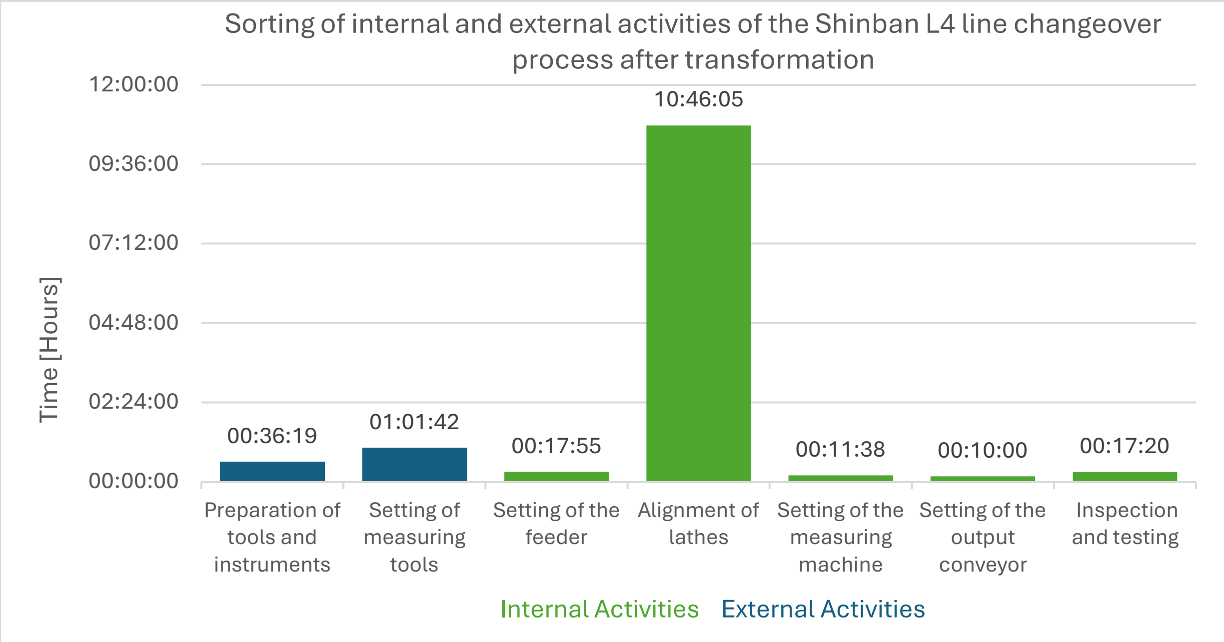

Figure 6 Sorting of internal and external activities of the Shinban L4 line changeover process after transformations [Source: Authors]

3.7 Elimination of Wastes

During the examination of the changeover process on the Shinban L4 lathe line, several types of waste were identified. Eliminating these wastes can contribute to reducing the total time required for changeover. Wastes include unnecessary movements, waiting, and searching. Standardizing the changeover process on the Shinban L4 line would facilitate the effective training of new employees. Implementing a changeover standard would also help align procedures among the various changeover operators, eliminating unnecessary contemplation over subsequent steps.

Relocation of the box with spare screws. During the changeover, the operator lost time walking to retrieve spare screws that were placed away from the workstation. Relocating these screws directly to the workstation could save 110 seconds, significantly contributing to the efficiency of the process.

Use of a foam tool organizer. Disorganized tools at the workstation reduced the efficiency of the changeover. By introducing a foam organizer, clarity would improve, potentially saving 1 minute and 30 seconds from the total changeover time.

Placement of a walkie-talkie at the workstation. Installing a walkie-talkie at the Shinban L4 workstation and in the measurement workshop would allow for quicker communication between the changeover operator and the measurer, eliminating time waste during measurements and transitions. The estimated time savings are 15 minutes and 2 seconds.

Introduction of shared tools**.** Each changeover operator used their own tools, causing time losses during shift changes. By implementing shared tools that would remain at the workstation even during shifts, approximately 5 minutes and 47 seconds could be saved. All identified time savings achieved through the elimination of individual wastes are summarized in the following Table 1. This table provides a detailed overview of time savings for each implemented measure and highlights the overall impact of these improvements on enhancing the changeover process of the Shinban L4 line.

Table 1 Summary of Waste Elimination Proposals [Source: Authors]

Proposal for Waste Elimination	Potential Savings [hrs]	Total Potential Savings [hrs]
Standardization	0:00	
Relocation of the box with spare screws to the Shinban L4 workstation	0:01:50	
Use of a foam tool organizer	0:01:30	0:32:40
Placement of a walkie-talkie at the Shinban L4 workstation and in the measurement workshop	0:23:33	
Introduction of shared tools	0:05:47	

3.8 Elimination of Downtime

For the proper functioning of production processes, it is crucial to minimize downtime, which can occur due to poor time management, lack of personnel, or unnecessary work interruptions. One significant source of downtime is the failure to maintain work discipline. Observations revealed that workers often exceed the allotted break times. For example, a worker on the morning shift extended their lunch break by 21 minutes and 25 seconds. Another significant downtime occurred between the departure of the morning shift and the arrival of the afternoon shift, lasting 45 minutes and 9 seconds, during which there was no operator at the line. In total, adhering to work discipline could save up to 66 minutes and 34 seconds.

Another source of downtime is the improper distribution of tasks during the changeover process. It often happened that the changeover operator had to leave the Shinban L4 workstation to assist an operator on a neighboring line who was unable to adjust machine settings. The changeover operator was thus fulfilling a supervisory role, which caused delays in their primary task. Reassigning this supervisory role to a second changeover operator or an available maintenance technician could potentially save 1 hour, 37 minutes, and 8 seconds of the total changeover time. This proposal closely ties in with other measures aimed at improving efficiency.

A significant obstacle to efficient changeovers was the combination of tasks performed by the changeover operator and the maintenance technician. In the current situation, the changeover operator often left the workstation to perform repairs on other lines, which significantly prolonged the entire process. Introducing a dedicated maintenance technician during the changeover would allow the changeover operator to focus solely on their task while the technician handles necessary repairs.

As part of the changes, an inexperienced young maintenance technician could be replaced by a more experienced changeover operator, further improving coordination. This could save an additional 1 hour, 28 minutes, and 28 seconds. The following Table 2 provides a clear overview of the identified sources of downtime, along with proposed solutions and the estimated time savings from their elimination.

Table 2 Summary of Proposals for Downtime Elimination [Source: Authors]

Proposal to Eliminate Downtime **Increasing worker discipline**	Potential Savings [hrs] **1:06:34**	Total Potential Savings [hrs]
Changing the supervision of operators on production lines	1:37:08	4:12:10
Ensuring the presence of at least one maintenance technician besides the changeover operator during changeovers	1:28:28	

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3.9 Reduction of Internal Activity Times

Reducing the time of internal activities is crucial for improving the efficiency of the production process. This goal is achieved through the optimization of work procedures, standardization, and the use of appropriate tools. In the case of the Shinban L4 line, it was found that workers performed most tasks manually, leading to unnecessary time wastage. Several opportunities were identified to shorten these tasks by using electric and more efficient tools.

One option is to use a cordless drill for tasks that previously required manual tools, such as wrenches and Allen keys. However, for some activities, the use of electric tools is limited by space constraints, making their application not always feasible. Nevertheless, where possible, significant time savings were observed. Analysis showed that the worker spent a total of 57 minutes and 45 seconds on these tasks, with 44 minutes and 43 seconds dedicated purely to screwing. Based on measurements, it was concluded that the use of a cordless drill would reduce screwing time by approximately 50%, representing a savings of 22 minutes and 21 seconds.

Another area for improvement is the lubrication process of lathe components, which workers perform either manually or with a screwdriver. These methods are time-consuming and impractical. Using a grease gun reduced the time required for lubrication. Upon repeated video analysis, the pure lubrication time was measured at 10 minutes and 29 seconds. Based on the analysis, it was determined that the potential time savings could be up to 45%, representing a reduction of 4 minutes and 43 seconds.

Currently, traditional wrenches are used on the changeover lines, which are time-consuming and impractical for repetitive tasks. Ratchet wrenches offer a more efficient alternative, enabling faster screwing. Analysis showed that replacing traditional wrenches with ratchet wrenches could potentially reduce the time by approximately 6%, representing a savings of 3 minutes and 14 seconds. The following Table 3 provides a clear summary of the time-saving values for the implemented improvements.

Table 3 Summary of Proposals for Reducing the Duration of Internal Activities [Source: Authors]

Proposal for Reducing the Duration of Internal Activities	Potential Savings [hrs]	Total Potential Savings [hrs]
Cordless Drill	0:22:21	
Grease Gun	0:04:43	0:30:18
Ratchet Wrenches	0:03:14	

To implement the proposed steps aimed at reducing internal activities and streamlining the work process, an investment of 480.45 euros is required. This investment consists of purchasing modern and efficient tools, which will not only contribute to increased productivity but also reduce the time needed to perform individual tasks. Considering the expected time savings and efficiency improvements, this investment is a very reasonable step, which can pay off significantly in the long run.

4. Economic and Technical Evaluation of the Proposals

In the economic and technical evaluation, it is important to assess not only the potential time savings but also how these savings are achieved. This chapter is divided into two main sections. The first section deals with time savings that are possible without the need for additional investments. These improvements are often achieved through optimizing existing work processes and using current resources more efficiently. This demonstrates that significant process efficiency can be achieved even without large investments. The second section focuses on time savings that require additional investments to modernize tools and technologies. Although these investments represent initial costs, they can lead to significant improvements in efficiency and productivity in the manufacturing process.

4.1 Time Savings of the Variant without Necessary Investment

Without requiring any investment, the time saved per changeover reached 4 hours, 21 minutes, and 17 seconds, which represents 37.87% of the total changeover time, after deducting break time. This time saving is clearly displayed in the following Table 4.

Table 4 Evaluation of Time Benefits of the Variant without Necessary Investment [Source: Authors]

Operation Name	Total Changeover Time [hours]	Total Changeover Time Reduced by Breaks [hours]	Duration of Potential Savings [hours]	Percentage of Potential Savings [%]	Potential Changeover Time After Savings [hours]
Changeover	14:30:00	13:30:00	4:21:17	37:87%	9:08:43

4.2 Time Savings of the Variant with Necessary Investment of €480.45

By applying the SMED method to the changeover process of the Shinban L4 lathe line, a time saving of 5 hours, 6 minutes, and 37 seconds was achieved, corresponding to 44.43% of the total changeover time after deducting break times, as shown in Table 5.

Table 5 Evaluation of Time Savings of the Variant with Necessary Investment [Source: Authors]

Operation Name	Total Changeover Time [hours]	Total Changeover Time Reduced by Breaks [hours]	Duration of Potential Savings [hours]	Percentage of Potential Savings [%]	Potential Changeover Time After Savings [hours]
Changeover	14:30:00	13:30:00	5:06:37	44:43%	8:23:23

4.3 Potential Monthly and Annual Time Savings after Implementing the SMED Method

The potential monthly and annual time savings were calculated based on historical data from the company, analyzing a 12-month period (January 2021 – January 2022). This data served as the basis for estimating the potential time savings during the changeover process. From the following Table 6, it can be seen that by applying the SMED method, the time savings for the variant without necessary investment would amount to 13 hours, 3 minutes, and 51 seconds, with an annual time saving of 156 hours, 46 minutes, and 12 seconds. In the variant with an investment of €480.45, the potential savings would reach 15 hours, 19 minutes, and 51 seconds, translating to an annual savings of 191 hours and 39 minutes.

Table 6 Potential Monthly and Annual Time Savings after Implementing the SMED Method [Source: Authors]

Changeover Variant	Average Number of Changeovers for the Shinban L4 Line per Month	Potential Time Saved per Month [hours]	Potential Time Saved per Year [hours]
Without Necessary Investment	3	13:03:51	156:46:12
With Necessary Investment of €480.45	3	15:19:51	191:39:00

4.4 Financial Savings

The total financial benefit in the form of potential revenue increase is presented in the following Table 7.

Table 7 Potential Annual Revenue Increase from Individual Variants [Source: Authors]

Variant of Sorting	Potential Annual Time Savings [hours]	Average Weight of the Ring (kg/unit)	Average Number of Rings Produced (units/hour)	Material Price (€ /kg)	Selling Price (€ /kg)	Annual Wage Savings Due to Reduced Sorting Time	Potential Annual Revenue Increase (€)
Without Necessary Investment	156:46:12	0,085	95	1,40 €	2,80 €	1 354,61 €	4 899,17 €
With Necessary Investment of 480.45 €	191:39:00	0,085	95	1,40 €	2,80 €	1656,00 €	5 989,20 €

The estimated potential monetary benefit in the form of increased annual revenues amounts to €4,899.17 for the variant without the necessary investment and €5,989.20 for the variant with a necessary investment of €480.45. The difference in potential monetary benefits between the individual variants is €1,090.03, making the variant with the necessary investment of €480.45 the more favorable option.

Conclusion

The study focused on optimizing the changeover process of the Shinban L4 lathe line using SMED (Single-Minute Exchange of Die) techniques. The application of the SMED method led to the transformation of internal activities into external ones, while also reducing activities that could not be externalized. This approach resulted in a potential reduction of the total changeover time by 5 hours, 6 minutes, and 37 seconds, which represents 44.43% of the total time. The estimated investment for implementing these changes is €480.45. Based on the time savings, the annual savings are estimated to be 191 hours and 39 minutes, as well as a potential increase in company revenues of €5,989.20 per year. These results indicate that the application of the SMED method can significantly improve changeover efficiency and overall production productivity. In conclusion, we can state that the implementation of SMED represents a promising step towards optimizing the production process, contributing to the sustainability and competitiveness of businesses in a dynamic economic environment.

Acknowledgments

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