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CASE STUDY: USING LEAN MANUFACTURING TOOLS TO IMPROVE THE EFFICIENCY OF THE BIESSE TECHNO LINE FDT MACHINE

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The article presents a detailed study of the application of lean manufacturing tools at the manufacturing company Alfa to improve the efficiency of the Biesse Techno Line FDT machine. The study focused on using SMED techniques, the 5S methodology, and TPM tools to reduce setup time and increase overall machine performance. The research included process analysis, external and internal setup, transformation, and the implementation of improvements. The operator''s workstation was also enhanced by applying the 5S methodology to increase efficiency, ergonomics, and safety. The issue of unplanned downtime was resolved through the use of TPM tools and a schedule of activities. The study was designed not only to improve the performance of the Biesse Techno Line FDT machine in wood processing, but also to have a positive impact on aspects of sustainable development. The reduction in setup time contributed to a reduction in energy and material consumption and waste reduction. Additionally, improving the organization of the workstation and eliminating waste contributed to better ergonomics, safety, and employee health. This study aligned with the concept of sustainable development, which aims to achieve economic efficiency, minimize environmental impact, and provide social benefits.

Keywords: lean management, sustainability, lean manufacturing, SMED, TPM, 5S method

1. INTRODUCTION

The present article features a case study on the application of *lean manufacturing* tools at a manufacturing company, Alfa, in order to improve the efficiency of

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the Biesse Techno Line FDT machines. The main goal was to improve the efficiency and minimize the changeover times for the Biesse FDT machines, as well as maximize their potential and reduce downtime.

Alfa decided to implement a *lean manufacturing* strategy to optimize the use of resources and increase the efficiency of the Biesse Techno Line FDT machines. The study aimed to optimize the efficiency of the Biesse Techno Line FDT machines in the context of wood processing using SMED techniques, the 5S method and the TPM approach.

The study focused on the use of SMED (*Single Minute Exchange of Die*) techniques to shorten the changeover time for the machines and minimize the number of tools used. The procedure for improving the changeover process included four stages: process analysis, external and internal changeovers, changeover transformation and the introduction of improvements (Kruczek, Żebrucki, 2012).

Another area of the study focused on the workstation of the operator handling the Biesse Techno Line FDT machine. The use of the 5S method was suggested in order to increase work efficiency, improve ergonomics and ensure safety at the workstation. The implementation of sorting, setting in order, cleaning (shining), standardizing and sustaining was intended to contribute to the improvement of processes at the workstation.

The last aspect of the study was the problem of unplanned machine downtime, which had a negative impact on the overall efficiency of the production line. The use of the TPM (*Total Productive Maintenance*) method was proposed, which aimed to involve all members of the company to ensure maximum efficiency of the machines. The intention of creating a schedule of washing, inspection and lubrication was to minimize the risk of critical machine faults leading to unplanned downtime.

The results of the study were expected to contribute to an improvement in the overall efficiency and effectiveness of the Biesse Techno Line FDT machines in the context of wood processing. The implementation of SMED, the 5S method and TPM was aimed not only at increasing the efficiency and effectiveness of production, but also at minimizing any negative impact on the environment and taking into account social aspects. Reducing the changeover time and minimizing the number of tools would contribute to a more efficient use of resources such as energy and raw materials, which would have a positive impact on the environment. In addition, improving the ergonomics of the operator's workstation and ensuring safety would result in good working conditions and the good health of employees, which is part of corporate social responsibility. The introduction of *lean manufacturing* tools and taking care to minimize unplanned machine downtime would also contribute to increased efficiency, leading to a reduction in energy consumption, waste generation and greenhouse gas emissions. Therefore, it was expected that this study would lead to conclusions and actions consistent with the concept of sustainable development since they resulted from the pursuit of economic efficiency, environmental protection and benefits for society.

2. LEAN MANAGEMENT AND THE CONCEPT OF SUSTAINABLE DEVELOPMENT

The introduction of innovations is indispensable for manufacturing companies that strive to achieve competitiveness in a changing market. Such innovations are aimed at improving operational efficiency, minimizing material losses and developing the awareness and skills of staff (Gutowska, 2014). In this context, methods and systems used to achieve these goals are constantly evolving, drawing on years of experience.

The Toyota Production System is based on two fundamental pillars. The first one is *Just in Time* (JIT). Its main goal is to eliminate waste by providing the necessary tools and materials at the right time and in the right quantity, thus minimizing waiting time. Through the use of JIT, Toyota strives to eliminate any unnecessary delays and interruptions in the production process (Sugimori et al., 1977; Grudowski, 1996).

The second pillar is *Jidoka*, also known as automation. Its aim is to design production systems in such a way that they enable the detection and elimination of errors and deviations from established standards during the production process. *Jidoka* principles allow the production line to stop in the event of failures, and also facilitate the identification of defective areas. Thanks to this, Toyota achieves high production quality and minimizes the risk of faulty products.

The Toyota Production System is often identified with the concept of *lean production*, which has successfully spread to manufacturing enterprises around the world (Dekier, 2017). The implementation of *lean* management is not possible in organizations that are reluctant to change and unwilling to adjust their way of working. In order to achieve maximum benefits from *lean* implementation, one should focus on the "soft" aspects of management, especially on using the knowledge of employees who are directly involved in the production process (Piasecka-Głuszak, 2013). An important factor hindering the introduction of this methodology is often limited understanding and application.

Lean Management is a pioneering approach that has emerged as the dominant tool in achieving operational excellence. Faced with growing challenges related to limited resources, climate change, and rising societal expectations, organizations are increasingly motivated to pursue both operational excellence and sustainability (Maginnis, 2021; Pradziadowicz, Zaremba, 2017). Attempts have been made to show examples of how these two perspectives can coincide and mutually enrich each other.

Eliminating waste is the foundation of *Lean Management* and a key aspect of operational excellence. Innovative methods for identifying, analyzing and eliminating waste, such as *Value Stream Mapping* and cause-and-effect analysis, can be considered tools used to achieve this goal. The first convergence between *Lean Management* and the concept of sustainable development is their joint emphasis on operational efficiency and minimizing of waste. *Lean Management*, by eliminating unnecessary processes and activities, aims to maximize value for the customer with the minimal use of resources. In turn, the concept of sustainable development emphasizes the optimal use of natural resources and a reduction in the ecological footprint generated. Both these perspectives strive to reduce losses, optimize processes and ensure long-term effectiveness (Soliński, 2019; Świtek, 2013; Yusup et al., 2015).

In the context of *Lean Management*, the pursuit of operational excellence constantly drives organizations to introduce innovations and improve processes (Wiśniewski, 2010; Pawlak-Wolanin, Buchta, 2019). The methods and tools used for this purpose include methods of continuous improvement, such as *Kaizen* (a philosophy of continuous improvement), *Poka-Yoke* (error proofing) and *Hoshin Kanri* (managing goals and guidelines). Lean Management and the concept of sustainable development strive to achieve process optimization with minimal negative impact on the environment. Lean Management, through the use of techniques such as *Value Stream Mapping* or value stream analysis, aims to eliminate unnecessary activities, reduce the consumption of energy and raw materials, as well as minimize the generation of waste. The concept of sustainable development, in turn, assumes development based on the principles of environmental protection, ie. preventing ecosystem degradation and reducing greenhouse gas emissions. Both these perspectives strive for the healthy development of an organization in harmony with the environment (Schwarz et al., 2021; Dieste, Panizzolo, 2019).

As part of *Lean Management*, taking the human factor into account is crucial for the success of an organization. One can single out here strategies and techniques which promote employee engagement, such as *A3 Problem Solving* (solving problems in a holistic way), *Job Instruction Training* and *Kamishibai* (the visual audit method). Both *Lean Management* and the concept of sustainable development attach great importance to social responsibility and employee engagement. *Lean Management* promotes a culture of continuous improvement, encouraging employees to actively participate in identifying problems, introducing innovations and taking improvement measures. The concept of sustainable development, in turn, emphasizes the importance of an ethical approach to business, taking into account the interests of the local community and creating jobs based on fairness, equality and security. Both these perspectives support the creation of value not only for an organization, but also for society as a whole (Kwiatkowski et al., 2016; Dubicki et al., 2017).

In addition, parallels between *Lean Management* and the concept of sustainable development can also be drawn in their approaches to creating value for the customer and meeting social needs. *Lean Management* focuses on providing products and services of the highest quality that meet the expectations and needs of customers. The concept of sustainable development adds an additional dimension, encouraging organizations to create products and services that are not only attractive to customers, but also contribute to social welfare and environmental protection (Niewiadomski, Sterna, 2011; Kaźmierczak, Kamińska, 2017).

An analysis of the convergence of *Lean Management* goals and the concept of sustainable development shows that these two perspectives are not contradictory, but complementary. Operational efficiency, social responsibility, process optimization and customer value are elements that both these perspectives share. The introduction of *Lean Management* principles in the context of the concept of sustainable development allows organizations to achieve operational excellence in a manner consistent with the natural environment and community. We conclude that a harmonious combination of these two perspectives can contribute to the creation of organizations of the future that are not only competitive in the market, but also respond to current social and environmental challenges.

3. RESEARCH METHODOLOGY

The authors of the study adopted goals and assumptions that were achieved through the use of selected research methods and techniques. Observations were made throughout the production process and time measurements were taken. In addition, analysis of source documentation was based on examination of the operating instructions and job cards. Finally, the comparative analysis was aimed at presenting the results before and after the introduction of the proposed improvements.

In the context of the tools used in the study, the Pareto analysis and a heat map were utilized. The Pareto analysis, also known as the 80/20 rule, states that about 80% of consequences come from 20% of causes. In the context of management and business, this means that most results (such as profits, losses, and errors) are generated by a relatively small share of the activities or resources (Koch, 1999). The Pareto analysis was used to create a diagram that identified key factors affecting production efficiency. Meanwhile, a heat map is a graphical representation of data in which the values of individual points are represented by colours. It is an effective tool for visualizing complex data sets, allowing for a quick understanding of patterns, trends and anomalies. A heat map was used to graphically present the results of the analysis of the timing of particular steps in the machine changeover, which made it possible to quickly identify which steps took the longest amount of time and which the shortest. This helped to identify priority areas during the implementation of the SMED tool.

The main focus of the study was the production line consisting of two Biesse TECHNO LINE FDT machines (Nos. 139 and 140). The task was to improve the efficiency of these machines at Alfa. The Biesse TECHNO LINE FDT is a machine with automatic through feed drills for processing top and bottom surfaces and four sides. The machines are known for their high efficiency in serial production and are designed for drilling lines with automatic loading systems.

4. CASE STUDY

The Alfa manufacturing company specializes in the production of ready-mix concrete, precast concrete elements and transport pallets made of glued paper. In addition, paper filling in the form of a "honeycomb" has become a key component of the production. In recent years, the company has expanded its activities to include the production of furniture elements from a honeycomb structure, also using paper filling. Today, Alfa is a renowned manufacturer of high-quality furniture components made of various materials, such as honeycomb structures, MDF, wood and chipboard. However, Alpha faces challenges, which include low efficiency and high waste rates.

Alfa has two Biesse TECHNO LINE FDT machines on its production line. As the number of elements to be processed has increased, both the quantity and complexity of changeovers have risen, leading to extended downtime. Unfortunately, the company has not yet introduced standardized changeover procedures, which results in waste. Each operator sets the machines according to his own preferences, and information on the configuration of the machines comes from private notes. Currently, the company processes 28 different elements on the machines, which differ in size, type of plate, and type and complexity of drilling.

In addition, the company does not have established schedules for the cleaning and maintenance of the machines. The drills are given a quick clean with compressed air at the end of each shift. This type of cleaning does not ensure the full efficiency of the machines, because dust and sawdust accumulate in the guides, worms and other moving elements, hindering the smooth movement of the machines in all axes. The maintenance and lubrication of the moving parts of the machines is carried out only when the line remains idle for a longer time. Therefore, the current condition of the machines affects the length of time needed for a changeover, and frequent downtime is caused by axes jamming as well as other minor failures, which hinder the proper functioning of the drills. All these factors negatively affect the overall level of production and lead to further cases of waste that could be avoided if proper maintenance and cleaning of the machines was carried out.

Pareto analysis

In order to introduce the SMED technique, an analysis of the production of all elements in the period from January to June 2022 was carried out. The analysis was focused on quantitative and performance-related aspects.

The Pareto analysis was used to determine which production elements had the greatest impact on the total production volume of Alfa and, consequently, on the process of machine changeover. On the basis of this analysis, the three main elements, the Nordli divider (268 883 pieces), Micke side (135 715 pieces) and Lack TV

Table 1. Production summary in the period January – June 2022

Element	Month						Total
	January	February	March	April	May	June	
Micke corner	7079	6881	–	2832	4594	4353	25 739
Fjanklinge side	8685	–	–	10 057	–	–	18 742
Cat house side	17 441	16 652	8714	6693	4625	–	54 125
Cat house top	3751	9573	2640	5683	–	–	21 647
Cat house back	7220	6088	3498	4330	3023	–	24 159
Micke side	**24 810**	**34 309**	**20 532**	**26 805**	**15 860**	**13 400**	**135 716**
Micke side MDF	5778	11 771	9571	8966	6807	2083	44 976
Nordli divider	**43 895**	**51 556**	**65 966**	**51 180**	**28 129**	**28 107**	**268 833**
Lack TV	**11 497**	**29 554**	**23 957**	**21 001**	**31 840**	**14 789**	**132 638**
Smastad bolt	13 215	–	15 992	5317	11 023	6930	52 477
Slakt 130 x2	1932	5348	9658	7953	8001	4311	37 203
Slakt headboard	1018	3297	9355	1768	2856	3917	22 211
Slakt shelf	5096	6597	–	–	–	–	11 693
Slakt underbed	11 425	4555	15 250	8529	11 205	17 726	68 690
Tufjord bottom	6725	2890	8383	8587	–	9084	35 669
Uppfora plinth	4420	2005	–	7390	–	–	13 815
Vihals back panel	4196	18 651	33 094	15 198	6313	–	77 452
Vihals bolt	1528	6144	15 101	–	–	–	22 773
Myllra side	–	6904	–	–	2425	9721	19 050
Slakt bottom panel	–	6158	–	–	–	–	6158
Total	**179 711**	**228 933**	**241 711**	**192 289**	**136 701**	**114 421**	

Source: authors' own development.

(132 635 pieces), showed the largest share in the total volume, which suggested that focusing on optimizing their changeover could bring the greatest benefits to production efficiency. The choice of the first element, the Nordli divider, as the subject of detailed analysis within the SMED technique, was dictated not only by its dominant share of production, but also in order to present the analysis in an orderly manner within editorial restrictions. For the sake of the clarity and conciseness of the article, the element which was most representative of the production challenges of the enterprise was selected, while emphasizing that the same methodology could be applied to analysis of the remaining elements.

Description of actions taken during the changeover

The process of machine changeover is a key element in the industrial conversion of devices, enabling a change from the current element to the desired one. The study analyzed the actions and procedures followed by operators during machine changeover to identify the key stages of this process. The study comprised a detailed analysis of the activities performed during changeovers, with a summary of the significant actions and time measurements presented in the tables.

Measurement of changeover times

Measurements were made during the changeover process of the Biesse TECHNO LINE FDT machine. They are summarized below and contain detailed data on the execution times for individual activities. These data were selected on the basis of the Pareto analysis and could be used to analyze the times needed for machine changeover and compared with other periods or average changeover times. As a consequence, it was possible to optimize the changeover process by identifying the activities that required more time and considering ways to shorten them. A heat map was used to graphically represent the values. The legend for the heat map is shown in Figure 1.

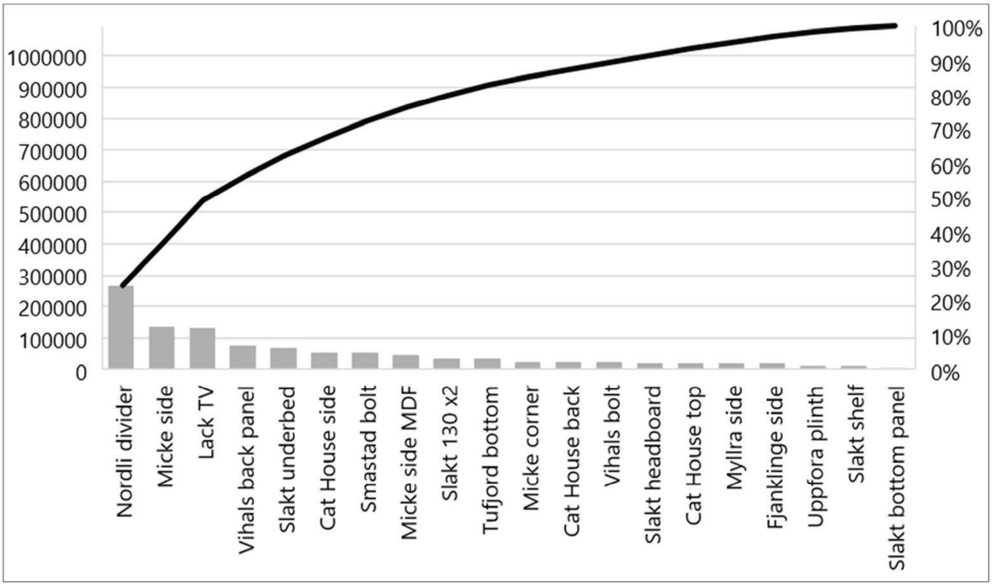

Fig. 1. The Pareto analysis for items manufactured from January to June 2022 (authors' own development)

Table 2. Timing of operations performed during the changeover of the Biesse machine No. 140 for the Nordli divider element together with their percentage share of the total changeover and a heat map

No.	Activity	Time average [s]	% share of the total changeover
1	Selecting a program and moving the bases to the target position	80	5.83%
2	Dismantling blowers	60	4.37%
3	Dismantling upper clamps	40	2.91%
4	Removing drill bits from drilling aggregates	180	13.11%
5	Dismantling the element detection sensor	90	6.55%
6	Unlocking the machine and setting the moving horizon to the safe position	50	3.64%
7	Dismantling the horizontal aggregate, bringing and installing the specific head required	240	17.48%
9	Removing drilling aggregates, installing required aggregates and moving them to the target position	144	10.49%
10	Fetching a reference element	40	2.91%
11	Setting the machine according to the reference element	139.2	10.14%
12	Assembling the element detection sensor	90	6.55%
13	Assembling side clamps at the target height	70	5.10%
14	Assembling upper clamps	30	2.18%
15	Shifting the moving horizon to the nominal dimensions of the element and securing the machine	120	8.74%
	TOTAL	**1373.2 s (22.89 min)**	**100%**

Source: authors' own development.

Table 3. Timing of operations performed during the changeover of the Biesse machine No. 140 for the Nordli divider element together with their percentage share of the total changeover and a heat map

No.	Activity	Time average [s]	% share of the total changeover
1	Selecting a program and moving the bases to the target position	80	5.97%
2	Dismantling blowers	60	4.48%
3	Dismantling upper clamps	70	5.22%
4	Removing drill bits from drilling aggregates	160	11.93%
5	Dismantling the element detection sensor	90	6.71%

cont. tab. 3

No.	Activity	Time average [s]	% share of the total changeover
6	Unlocking the machine and setting the moving horizon to the safe position	40	2.98%
7	Disassembling props at supports	70	5.22%
8	Assembling side clamps at the target height with screw extension	90	6.71%
9	Removing drilling aggregates, installing required aggregates and moving them to the target position	253.8	18.93%
10	Fetching a reference element	35	2.61%
11	Setting the machine according to the reference element	151.8	11.32%
12	Assembling the element detection sensor	90	6.71%
13	Assembling upper clamps	30	2.24%
14	Shifting the moving horizon to the nominal dimensions of the element and securing the machine	120	8.95%
	TOTAL	**1340.6 s (22.34 min)**	**100%**

Source: authors' own development.

Flowchart of the changeover of the Biesse TECHNO LINE FDT machine

The flowchart of the machine changeover process consisted of three sections: preparatory steps, disassembly operations followed by assembly operations, and operation tests. During preparation, the operator assessed the condition of the machine and set the programs for a new product. Disassembly required the removal of the unnecessary elements, and assembly – the installation of new components. Final tests confirmed that the machine was ready for production.

The purpose of creating a flowchart of the machine changeover process was to enable a faster and more efficient changeover, leading to a better use of resources. The presented flowcharts were developed for the selected and most frequently changed element in production. These flowcharts contained all the operations that the operator performed during changeover to the given element.

In addition, the flowcharts were colour-coded using a heat map, which made it possible to visually identify the most time-consuming operations during the changeover process.

In order to better understand and optimize the selected process, a summary was also created showing the percentage share of individual stages in the total changeover time for the machines. A heat scale was used, which visually illustrated the most time-consuming operations. Due to the editing limitations of the publication, the heat scale iss presented in greyscale.

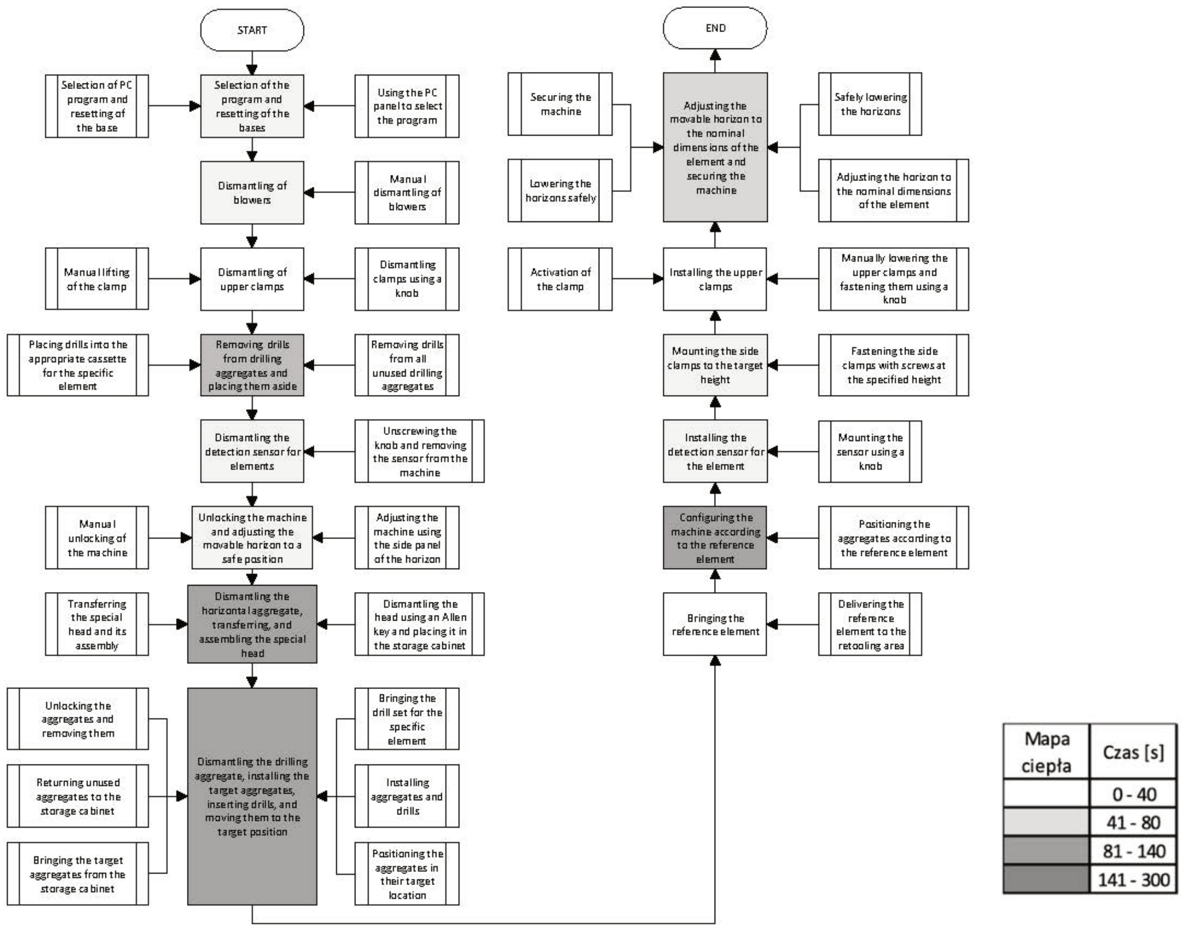

Fig. 2. Flowchart of Biesse No. 140 changeover for the Nordli divider element with a heat map (authors' own development)

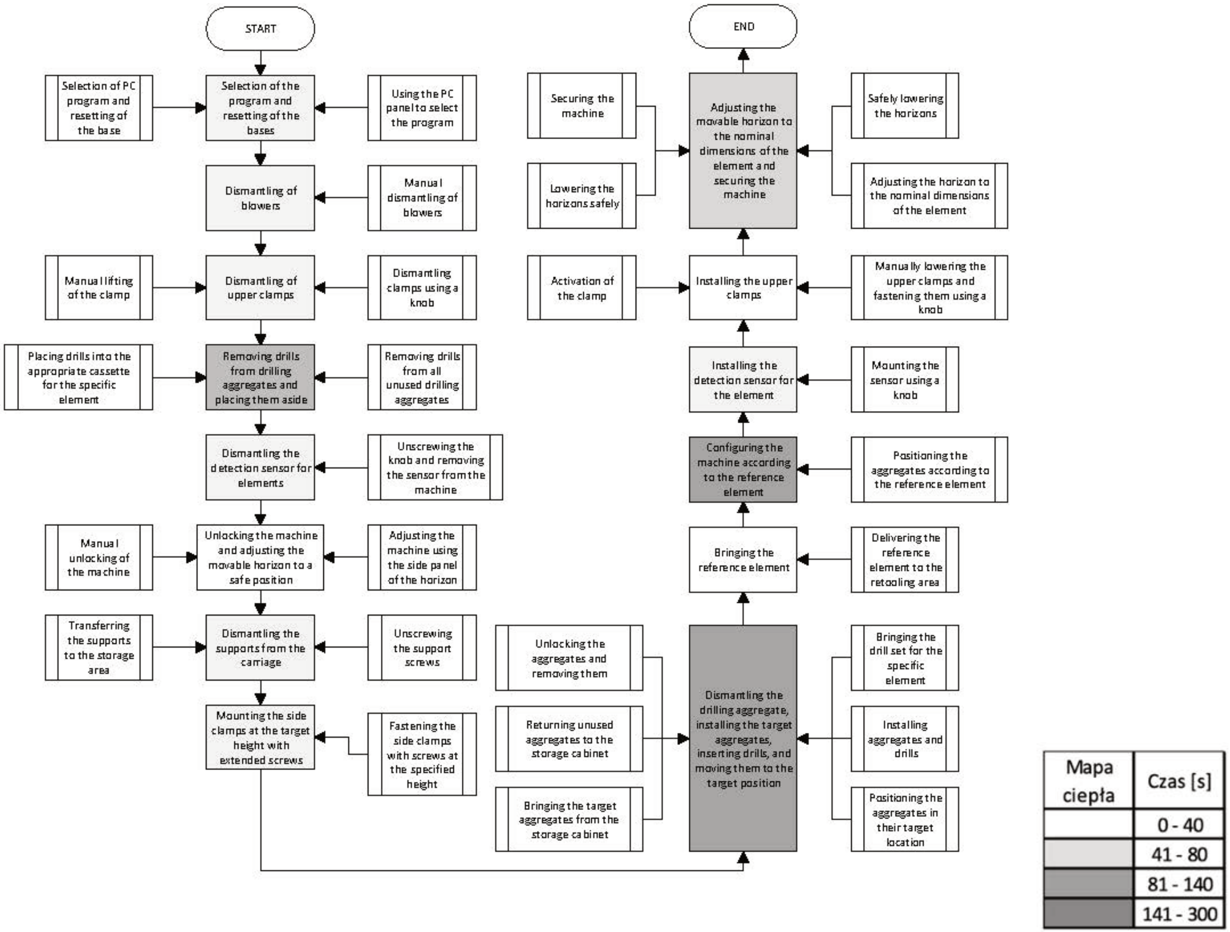

Fig. 3. Flowchart of Biesse No. 139 changeover for the Nordli divider element with a heat map (authors' own development)

Reduction in changeover times for the Biesse TECHNO LINE FDT machines

As part of the reduction in changeover times for the Biesse TECHNO LINE FDT machines, it was decided, after analyzing all the operations, that the study would focus on the three most time-consuming operations. The first operation was to remove and put away the drill bits from the drilling aggregates. The operator had to take an appropriate box from the cabinet next to the drill line, containing a set of drill bits assigned to the specific element. Then, the drill bits were removed by the operator and placed back into the box. The box containing the drill bits was returned to the cabinet, preparing a set of drill bits for use.

The next operation was the dismantling of the horizontal aggregate, and fetching and installing the specific head required. The operator dismantled the horizontal aggregate using an allen wrench and removed the two screws holding the aggregate. The removed aggregate was moved to the storage location, and then the operator retrieved the specific head required. This head was mounted by means of the allen wrench and two screws, placing it in position.

The third operation was to disassemble the drilling aggregates, install the chosen aggregates, insert the drill bits and move them to the target position. The supports to be changed were unlocked and the redundant drilling aggregates were removed. These were moved to the storage place in the cabinet next to the drill line. Next, the person responsible for the changeover of the machine selected the appropriate aggregates for the changeover element. The heads were mounted in the supports, moved to the target position in the X axis, and then secured against unwanted movement.

All operations related to fetching the elements needed for the changeover of the machine were transferred to the external changeover operation. Therefore, the operator undertook these activities before the start of the actual changeover, during production of the current element.

Changeover matrices

In order to reduce the changeover times for the most frequently produced element, it was decided that the process should be standardized by making the method for recording drill settings consistent. Up to this point, operators had used private notes, which often led to errors during reading and writing. This, in turn, caused frequent mistakes and unnecessarily prolonged the changeover process. In order to solve any problems with reading the settings, changeover matrices were introduced.

In this case, the changeover matrices were original boards containing settings for drills. They were presented in graphic form and showed drilling aggregates, used drill bits and accessories. At the top, in the middle, was the name of the element. The matrix was divided into two zones: for the first drill, Biesse No. 140, and for the second, Biesse No. 139. Such a division allowed the operators to use one universal matrix, on which information about both drills was located. 11-spindle aggregates were marked in grey, while 9-spindle ones were marked in white. The colours were used for quick identification by the operator. On the matrix, the positions of the drills were marked with an “X” and their size was shown next to them. The dashed line indicated the places through which transports in the X axis passed, while the places where props were used were marked with a bold, continuous line. Below the graphic representations of the heads, there was information on which support the presented aggregates should be used. In the further part of the matrix, there was information on the width of the setting of the moving horizon and the position of the supports in the X axis (the Y axis was set with the reference element). At the end of the matrix, there was a table with base positions. In addition, the matrices were equipped with additional notes for operators in order to help avoid problems.

A binder with changeover matrices was created as an integral part of standardization of the changeover process on the drill line. The matrices contained settings for all the manufactured components, allowing employees to gain easy access to

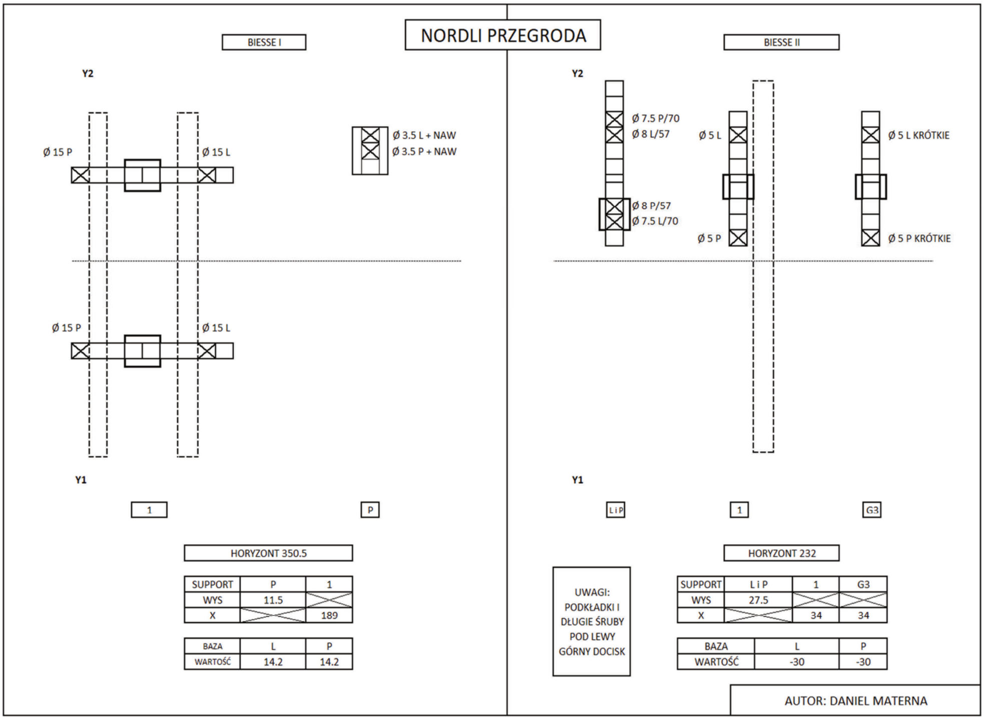

Fig. 4. Biesse No. 139 and Biesse No. 140 drill changeover matrix for the Nordli divider element (authors’ own development)

the necessary information and tools. Thanks to the standardization of settings, training new employees and delegating responsibilities between team members should become easier. Everyone should have access to clear guidelines. Standardization should also ensure the consistency of tools and procedures, thereby facilitating cooperation between operators.

Analysis of the type and causes of failure

In order to increase the efficiency of the Biesse TECHNO LINE FDT machines, data collected by the production plant in the period from January to June 2022 on the type and number of line failures were also analyzed. All failures were divided into categories, and their number was divided into individual months. The data are shown in the graph below:

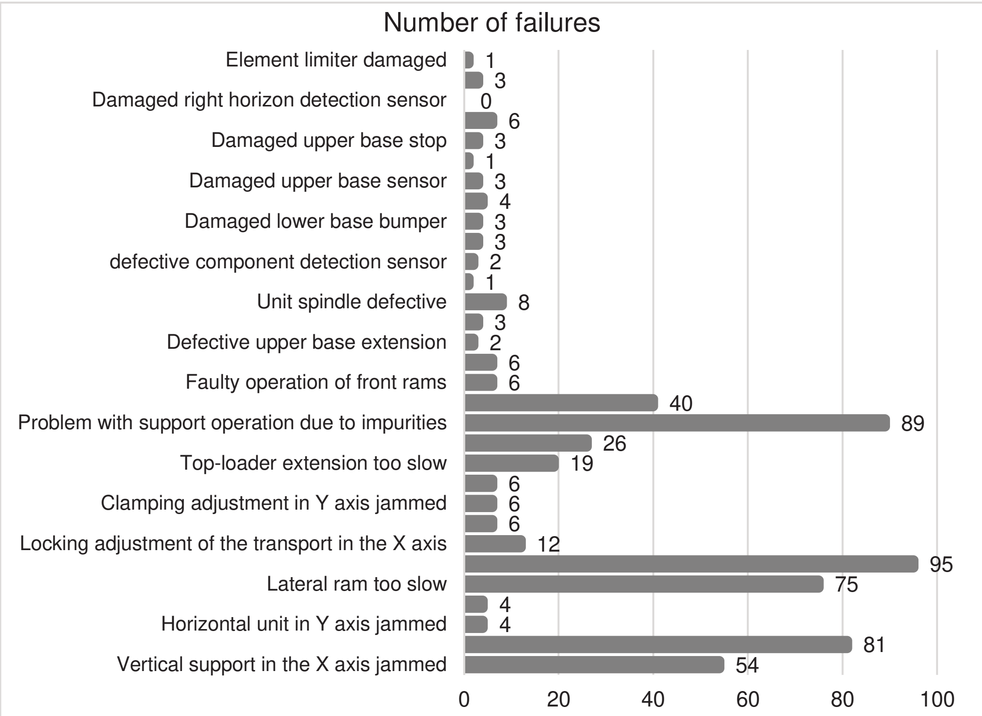

Fig. 5. The sum of failures occurring on the drill line in the period January – June 2022 (authors' own development)

The next stage of the analysis was to present the number of failures in the Pareto chart and to single out the most common faults:

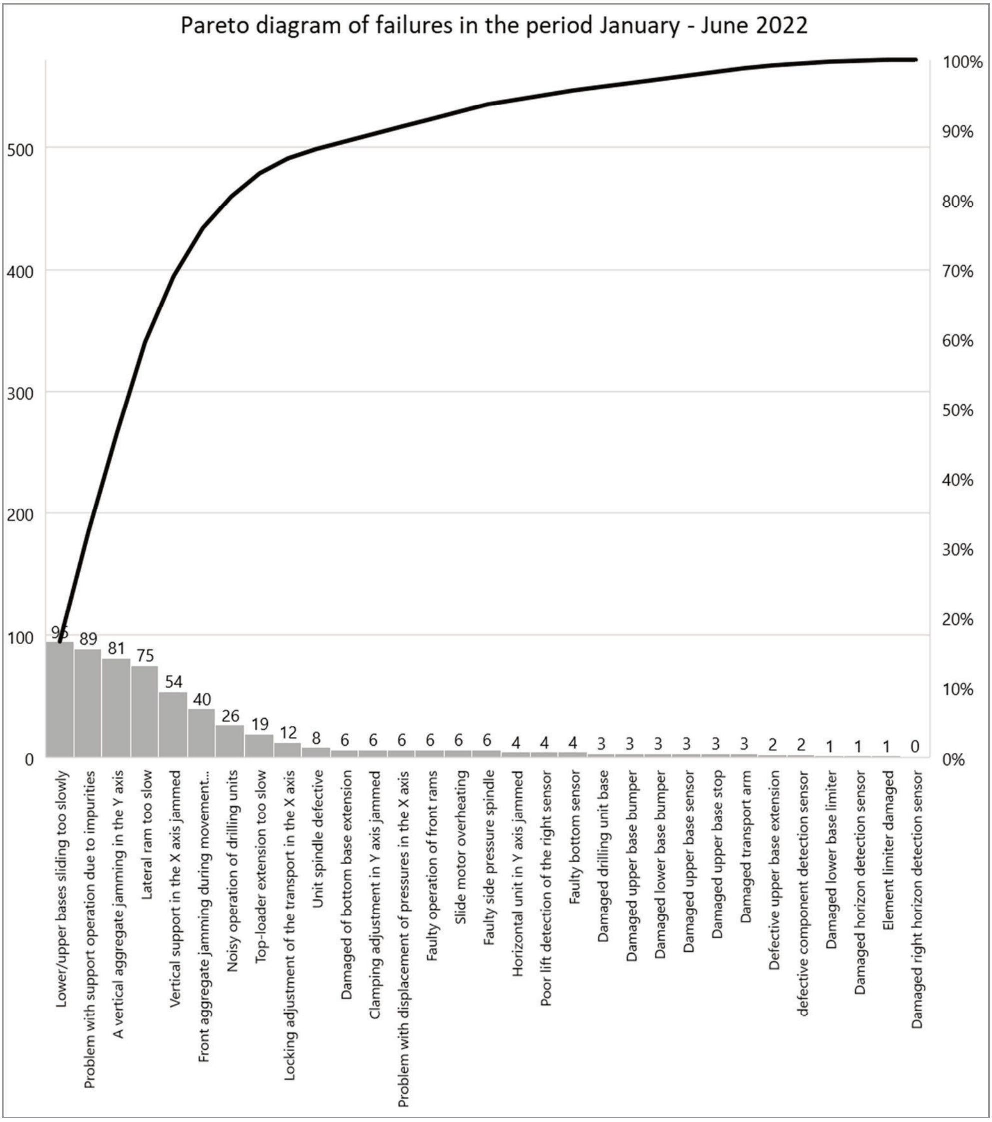

Fig. 6. Pareto analysis for failures occurring in the period January – June 2022 (authors' own development)

The Pareto analysis showed that the three most common faults were: lower/upper bases sliding too slowly – 95 times in 6 months; problems with the support operation due to impurities – 89 times; and the vertical aggregate jamming in the Y axis – 81 times. Less common failures contributing to machine downtime were mechanical damage to the line elements, such as: damaged element stop, damaged bottom base stop, and damaged thread of the support mounting screws. The last three types of failure occurred only once in the period from January to June 2022, which is why they were omitted from further analysis.

Changing the storage method for drill bits used for machine changeover

The method of storing drill bits was changed to a more legible and time-efficient one. Up until this point, drill bits had been stored in loose boxes which contributed to a mess in the cabinets. Operators looking for the right set of drill bits had a problem with the quick identification of a given set, which increased the time needed to access the tools, and with it the time for machine changeover. The state before any change is shown in the photo below.

Fig. 7. Way of storing drill bits before introducing a change
(authors' own development)

To eliminate this problem, two single boxes were created for the Biesse No. 140 and Biesse No. 139 machines. Both boxes were made of MDF with dimensions of 1050 × 850 × 20 mm, drilled with a Ø15 bit using a CNC machine. The distance between the holes was 32 mm in both the X and Y axes. A single matrix was able to store 832 drill bits ready for use. The drill bits in the previous boxes were assigned to new boards, zones for a given element were marked on them and they were labelled for faster identification (Figure 8). The boxes were placed on shelves under the table used to measure details. The boards prepared in this way reduced the mess in the cabinets by removing the old boxes. As a result of assigning drill bits on new boards to zones for specific elements, the drill bits needed for changeovers were identified faster. This, therefore, shortened the time needed to access the tools as well as machine changeover times. The change was positively received by the machine operators, and over time they got used to the new order, which made use of the new boxes intuitive for them.

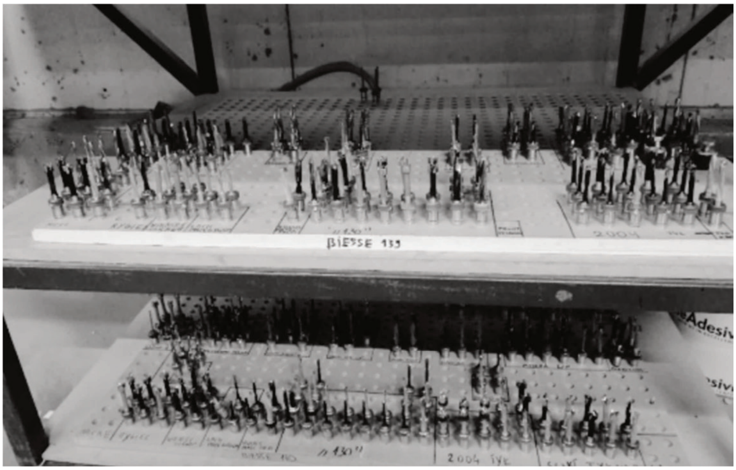

Fig. 8. Storage method for drill bits after introducing a change (authors' own development)

Instructions for external changeover operations

The next stage of implementation of the SMED method was responsible for the transformation of operations from internal to external changeovers. After analyzing the times and the flowchart for the machine changeovers, operations were identified which imposed unnecessary time losses on the operator, prolonging the process. The time wasted while transferring machine elements from the cabinets to the changeover area became evident. This included the following operations: removing drill bits from drilling aggregates, mounting props at supports, removing drilling aggregates, installing required aggregates and moving them to the target position. These activities were reduced by transferring them to the external changeover operation. External changeover operations are all activities that can be performed during production of the current element. The role of these operations is to shorten the machine changeover time by providing the required elements before starting the changeover itself. By providing the necessary elements in advance, the above-mentioned activities were shortened, and thus the overall changeover time for the machines was shortened as well. The operation of fetching the reference element was thus completely removed from the operations performed during the changeover. The given operation was transferred to the external changeover operation.

All external changeover operations were noted down and presented to the operators in the form of short instructions. A list with the indicated operations was printed and placed on the board along with other workplace instructions. The operators of the machines were obliged to perform these operations in order to shorten the changeover time for the machines.

CIL schedule creation

From the data obtained, it can be concluded that the cause of the most common downtime was contamination of the moving parts of the machines with impurities such as dust and sawdust, which were formed as a result of the normal operation of the drills of the Biesse TECHNO LINE FDT machines. In order to reduce the number of failures caused by impurities and eliminate their sources, a TPM tool was used, namely the CIL cleaning schedule, i.e. an updated and applied standard of cleaning, inspection and lubrication. After analyzing the information contained in the failure reports and selecting the places causing the most frequent downtime, cleaning schedules were created.

In order to better organize work during the activities planned in the schedule, the Biesse TECHNO LINE FDT machines were divided into three zones: the first consisted of the elements located on the left side of the machines, the second one included the elements on the right and the third was the middle zone. In each of the zones, the cleaning sites and the method of cleaning were assigned. For each of them, a list of tools needed to perform the activity was also prepared. For the zone on the left side of each machine, 13 areas requiring cleaning or lubrication were identified. Due to editorial restrictions, these schedules will not be discussed further.

The number of failures for the 3 selected fault types decreased as follows:

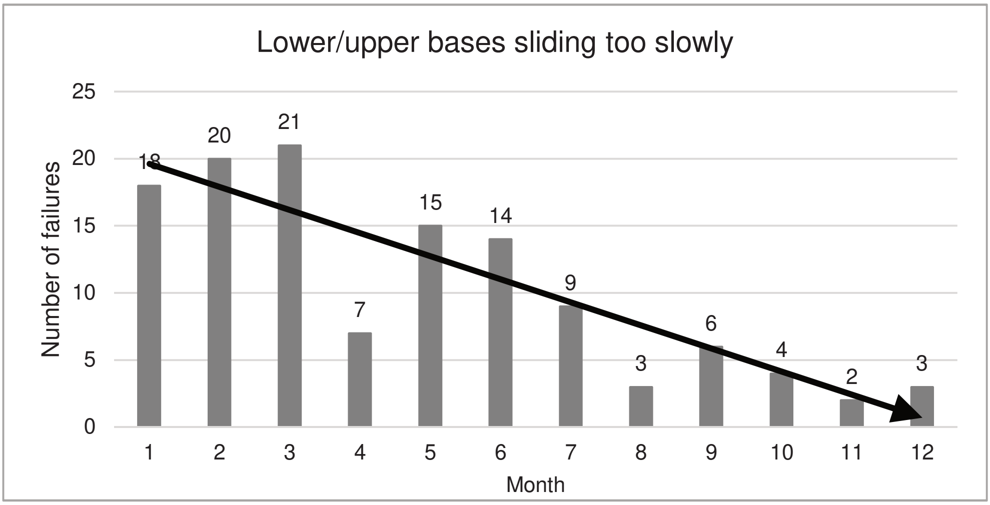

Fig. 9. Number of failures in 2022 for: Upper/lower bases sliding too slowly (authors' own development)

The number of downtimes resulting from a lower/upper base sliding too slowly was reduced from 95 (sum of failures in the first half of the year) to 27 (sum of failures in the second half of the year). The trend line showed a visible decrease in the number of failures since the beginning of the introduced changes. Before application of the CIL schedule, the failure occurred up to 21 times in one month (March). Thanks to regular cleaning, it was possible to reduce this number to 2. Such a result was obtained in November.

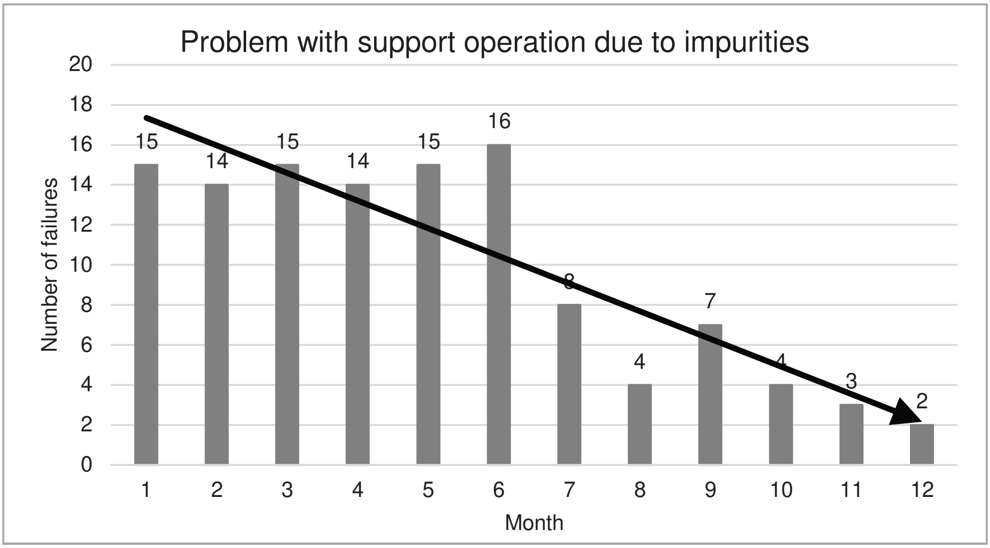

Fig. 10. Number of failures in 2022 for: Problem with support operation due to impurities (authors' own development)

The second most frequent issue was the problem with support operation due to impurities. As a result of the introduced changes, the total number of failures decreased from 89 in the period January – June to 28 in the period July – December. Figure 10 shows a clear downward trend. The implementation of CIL on the line reduced the number of failures occurring from the first month. Between June and July, it can be observed that there was a reduction of 50% in the occurrence of the failure, from 16 to 8. At the end of 2022, it was possible to reduce this number further to 2 occurrences per month.

The last type of failure included in the design analysis was the aggregate jamming in the Y axis. The defect occurred from 10 times in January to 16 times during June. After introducing changes on the production line, the occurrence of this type of failure was reduced to a maximum of 3 times in one month. Such a result was obtained in September and December.

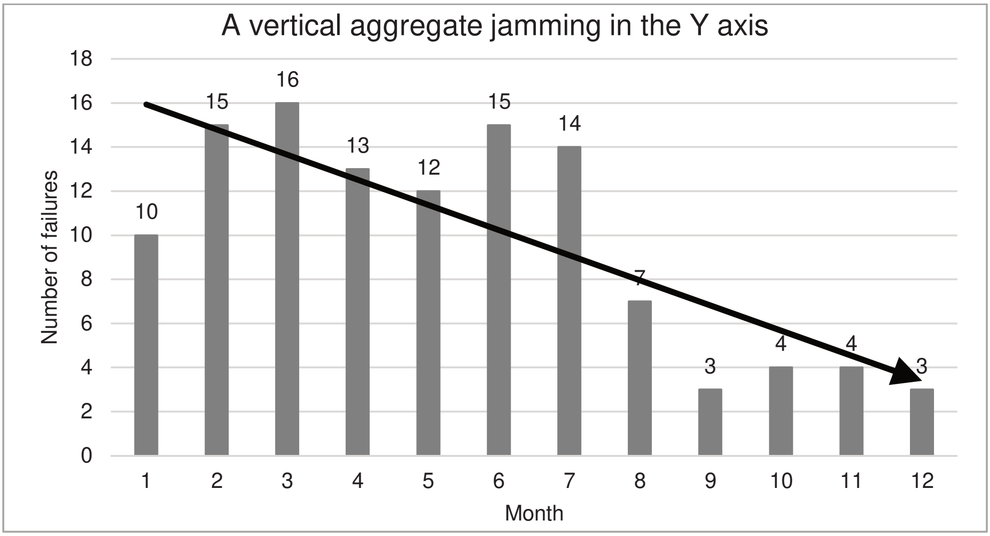

Fig. 11. The number of failures in 2022 for: A vertical aggregate jamming in the Y axis (authors' own development)

Result of improvements made

The main goal of the study was to increase the efficiency of the Biesse TECHNO LINE FDT machines by reducing changeover times using the SMED tool. The introduction of CIL schedules showed that regular inspection, cleaning and lubrication of the machines handled by the operators reduced their failure rates, which in turn increased the efficiency of the entire production line. The implementation of one of the TPM tools, namely CIL, significantly reduced the occurrence of the three most common failures. The first of the defects, a lower/upper base sliding too slowly, occurred a maximum of 6 times per month, which, compared to March 2022 in which the defect occurred 21 times, was a reduction of about 70%. Taking into account the month in which the defect occurred the least frequently, i.e. November 2022, the reduction in the occurrence of the defect was reduced by as much as 90% to 2 occurrences per month.

Another frquently occurring fault causing machine downtime was the problem with the support operation due to impurities. Through the CIL schedule, the occurrence of this type of failure was reduced from 16 in June to 2 in December. This resulted in a reduction of 87.5%. The decrease in the number of occurrences of the last type of failure, which was an aggregate jamming in the Y axis, went from 16 times a month to 3, giving a reduction of about 80%.

The above results confirmed that the introduction of systematic cleaning, lubrication and control of the condition of the machines through standardized CIL schedules significantly reduced unplanned machine downtime. During the introduction of this TPM tool, the focus was on reducing the occurrence of the three most common failures. The goal was achieved by eliminating the number of defects by an average of 85%.

The impact of the external changeover operation on the changeover time for the machines

An external changeover was proposed, which quite clearly affected the time needed for the machine changeover, as shown in the table below:

Table 4. Reduction in the changeover times for the Biesse machine No. 140 for the Nordli divider element

NEW CHANGEOVER METHOD				
No.	Activity	Time average [s]	Difference [s]	Time % reduction
1	Selecting a program and moving the bases to the target position	80	0	0.00%
2	Dismantling blowers	60	0	0.00%
3	Dismantling upper clamps	40	0	0.00%
4	Removing drill bits from drilling aggregates and putting them away	94.4	85.6	–47.56%
5	Dismantling the element detection sensor	90	0	0.00%
6	Unlocking the machine and setting the moving horizon to the safe position	50	0	0.00%
7	Dismantling the horizontal aggregate, installing the required head	207	33	–13.75%
8	Dismantling drilling aggregates, setting up required aggregates, inserting drill bits and moving them to the target position	61.4	82.6	–57.36%
10	~~Bringing a reference element~~	0	40	–100.00%
11	Setting the machine according to the reference element	139.2	0	0.00%
12	Assembling the element detection sensor	90	0	0.00%
13	Assembling side clamps at the target height	70	0	0.00%
14	Assembling upper clamps	30	0	0.00%
15	Shifting the moving horizon to the nominal dimensions of the element and securing the machine	120	0	0.00%
	TOTAL [s]	**1132**	**241.2**	**–17.56%**
	[MIN]	**18.87**	**4.02**	

Source: authors' own development.

As a result of the introduced improvements in the changeover process of the Biesse No. 140 machine to operate the Nordli divider element, a significant reduction in the duration of the operations was observed.

The first noteworthy achievement was the reduction by 85.6 seconds of the time needed to perform activity No. 4, which led to a reduction in time by 47.56%. The next step, which contributed to the shortening of the process, was the effective disassembly of the horizontal unit and the installation of the specific head required, which afforded a time advantage of 33 seconds, constituting a relative improve-

Table 5. Reduction in the changeover times for the Biesse machine No. 140 for the Nordli divider element

NEW CHANGEOVER METHOD				
No.	Activity	Time average [s]	Difference [s]	Time % reduction
1	Selecting a program and moving the bases to the target position	80	0	0.00%
2	Dismantling blowers	60	0	0.00%
3	Dismantling upper clamps	70	0	0.00%
4	Removing drill bits from drilling aggregates and putting them away	69.2	90.8	–56.75%
5	Dismantling the element detection sensor	90	0	0.00%
6	Unlocking the machine and setting the moving horizon to the safe position	40	0	0.00%
7	Disassembling props at supports	70	0	0.00%
8	Assembling side clamps at the target height with screw extension	90	0	0.00%
9	Dismantling drilling aggregates, setting up required aggregates, inserting drill bits and moving them to the target position	106.2	147.6	–58.16%
10	~~Bringing a reference element~~	0	35	–100.00%
11	Setting the machine according to the reference element	151.8	0	0.00%
12	Assembling the element detection sensor	90	0	0.00%
13	Assembling upper clamps	30	0	0.00%
14	Shifting the moving horizon to the nominal dimensions of the element and securing the machine	120	0	0.00%
	TOTAL [s]	1067.2	273.4	–20.39%
	[MIN]	17.79	4.56	

Source: authors' own development.

ment of 13.75% compared to the previous changeover method. It is also worth noting that operation No. 8 was shortened by 82.6 seconds, which resulted in a significant time reduction of 57.36%. In addition, in order to further optimize the process, the need to fetch the reference element by transferring this activity to the external changeover operation was waived.

Summing up, as a result of the introduced changes, the changeover process of the Biesse No. 140 machine to operate the Nordli divider element was shortened by 241.2 seconds, which led to a time gain of 4 minutes and 1 second. The overall time reduction in the entire process was 17.56%.

As a result of the introduced improvements in the changeover process of the Biesse No. 139 machine to operate the Nordli divider element, a significant reduction in operation time was observed. The operation of removing drill bits from the drilling aggregates and putting them away was reduced by an impressive 90.8 seconds. The percentage share of this operation in the entire process decreased by a significant 56.75% compared to the previous changeover method.

Another important change was the significant reduction in the time needed for activity No. 9 by 147.6 seconds, which resulted in an impressive time reduction of 58.16%. In addition, in order to further optimize the process, the need to fetch the reference element by transferring this activity to the external changeover operation was waived.

As a result of these improvements, the changeover process of the Biesse No. 139 machine to operate the Nordli divider element was reduced overall by 273.4 seconds, which means a significant time gain of 4 minutes and 33 seconds. The total percentage reduction in time in the entire changeover process was 20.39% compared to the previously used method.

Description of operations reduced by external changeover

The operations that were shortened by the use of the external changeover and their description are presented below:

1. Removing drill bits from drilling aggregates and putting them away: This is a necessary operation in any changeover. Thanks to the original method of storing drill bits, the time needed for this operation was significantly reduced. By creating a clear and intuitive box, machine operators did not waste time looking for a suitable place to put drill bits away, which was characteristic of the previous method.
2. Installation of props at supports: This operation, carried out during the changeover of the Micke side element on the Biesse No. 140 machine, was shortened by preparing the appropriate number of supports at the changeover point. As a result, suitable supports were available at the changeover stage, which saved time.
3. Fetching the reference element: This operation was present in all changeovers and it was fully transferred to the external changeover. The reference element was brought to the place of changeover during production of the current element, eliminating the need for a separate fetching operation.

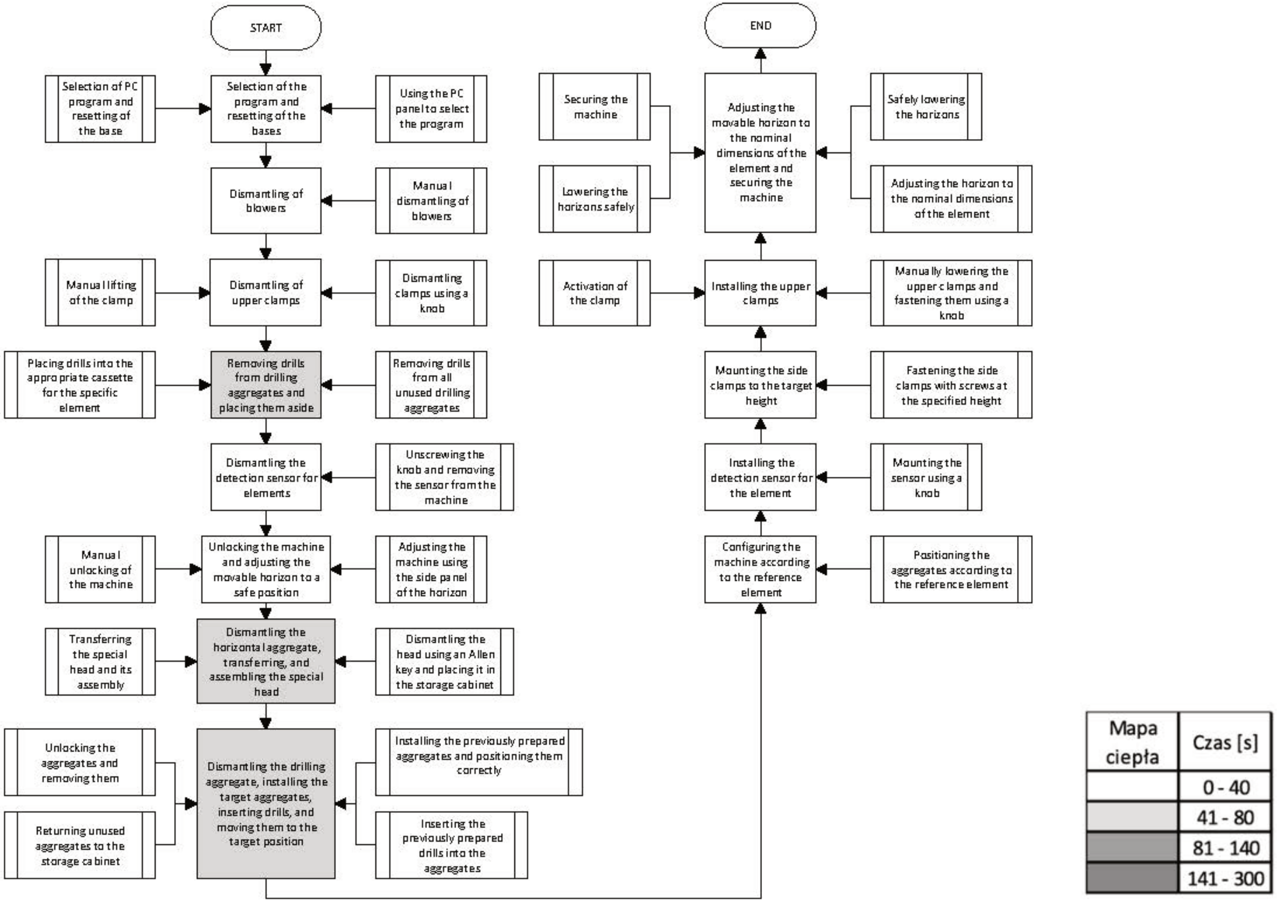

Fig. 12. Flowchart of reduced changeover operations for the Nordli divider element on the Biesse No. 140 machine (authors' own development)

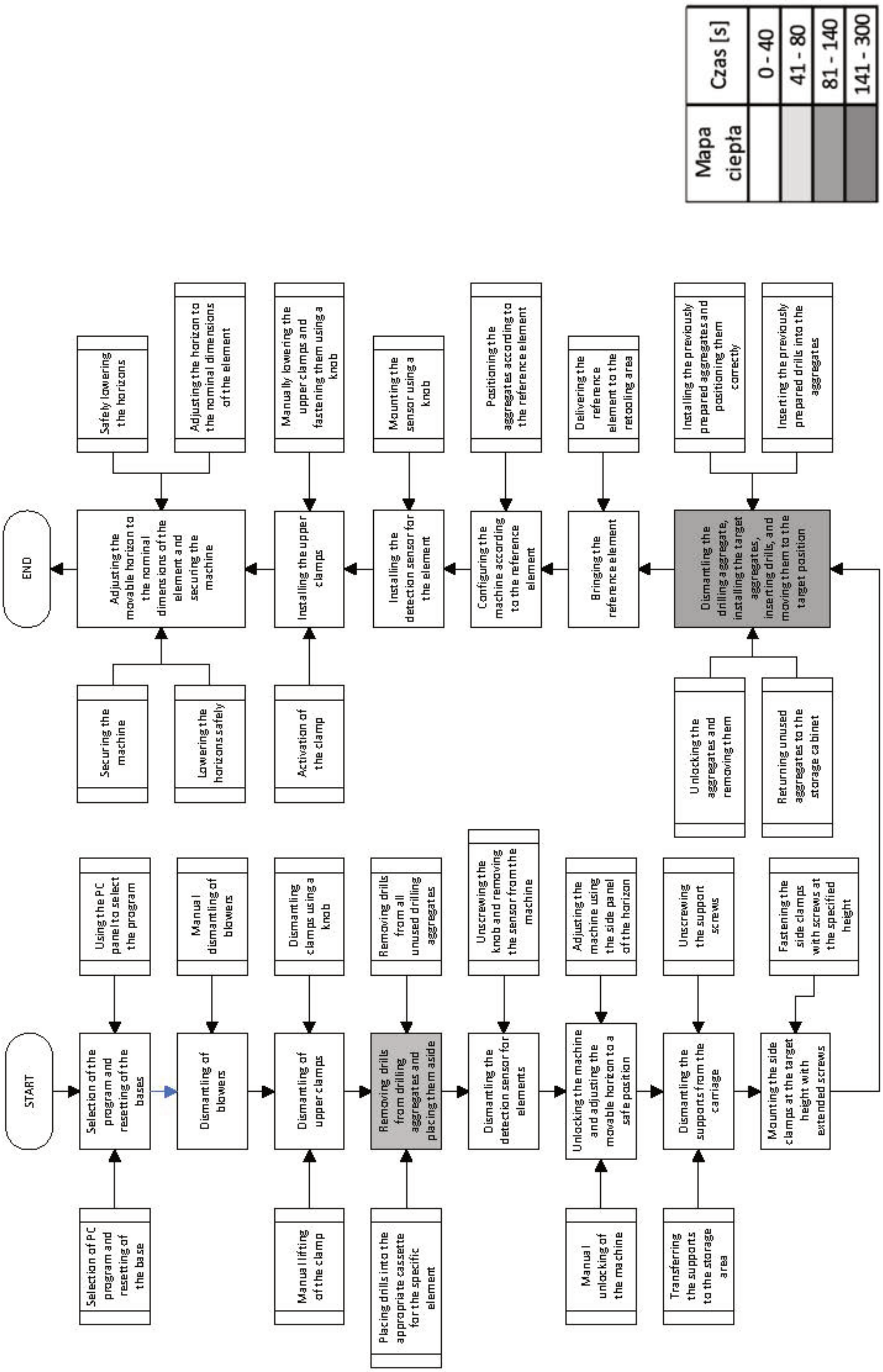

Fig. 13. Flowchart of reduced changeover operations for the Nordli divider element on the Biesse No. 139 machine (authors' own development)

4. Disassembling drilling aggregates, setting up required aggregates, inserting drill bits and moving them to target positions: This operation, performed during the changeover of elements, was significantly shortened by the provision of appropriate aggregates and drill bits at the place of changeover during the production of the current element. Improved access to tools in the cabinet was provided by introducing a new order in its interior.
5. Disassembling the horizontal aggregate and assembling the specific head required: This activity, which was part of the changeover of the Biesse machine No. 140 for the Nordli divider element, was shortened by delivering the required head to the place of changeover during production of the current element.

Flowchart of reduced changeover operations

As part of the conducted research, updated flowcharts were created, based on the new changeover methods for the Biesse TECHNO LINE FDT machines. These flowcharts showed the sequence of operations performed step by step during the changeover of the Biesse No. 139 and Biesse No. 140 machines in order to operate the Nordli divider element. Each step was divided into main activities and component activities. In order to visualize and identify operations that were changed or reduced, all such activities were marked with a light grey colour. These flowcharts were developed to present and better understand the activities that were optimized during the machine changeover process.

5. CONCLUSIONS

The study was carried out to justify the improvements introduced. Increasing the efficiency of the Biesse TECHNO LINE FDT machines by reducing changeover times using the SMED tool and implementing CIL schedules were key elements of this research.

The introduction of CIL schedules brought positive results in the form of reducing machine failure and increasing the efficiency of the entire production line. Systematic inspection, cleaning and lubrication carried out by the machine operators contributed to a reduction in the frequency of the three most common failures. For example, a defect associated with a lower/upper base sliding too slowly occurred a maximum of 6 times per month, which was a reduction of about 70% compared to March 2022, when the fault occurred 21 times. Similarly, support problems caused by impurities were reduced from 16 in June to 2 in December – a reduction of 87.5%. In the case of an aggregate jamming in the Y-axis, the number of occurrences of the fault was reduced from 16 times per month to 3, which was a reduction of about 80%.

The results of these tests confirmed that the introduction of systematic cleaning, lubrication and condition control of the machines through standardized CIL schedules significantly reduced unplanned machine downtime. The focus was on reducing the most common faults, achieving an average reduction in their occurrence by 85%.

In addition, the presentation of specific results and time gains in the context of shortening operations and the total changeover times for the Biesse No. 139 and Biesse No. 140 machines indicates the achievement of specific economic benefits. Reducing time means increasing work efficiency, reducing costs and the possibility of increasing production or saving resources.

The presentation of the updated flowcharts indicates the changes introduced in the machine changeover process, enabling a better understanding of the optimized activities. These flowcharts are an important tool for visualizing and identifying changes and reducing operations, and can be used in other production processes.

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STUDIUM PRZYPADKU: ZASTOSOWANIE NARZĘDZI LEAN MANUFACTURING W CELU POPRAWY EFEKTYWNOŚCI PRACY MASZYNY BIESSE TECHNO LINE FDT

Streszczenie

W artykule przedstawiono szczegółowe badanie dotyczące zastosowania narzędzi lean manufacturing w przedsiębiorstwie Alfa w celu poprawy efektywności maszyny Biesse Techno Line FDT. Badanie skupiło się na wykorzystaniu technik SMED, metodyki 5S oraz narzędzia TPM w celu skrócenia czasu przezbrojenia i zwiększenia ogólnej wydajności maszyny. Badanie obejmowało analizę procesu, przezbrojenia zewnętrzne i wewnętrzne, transformację oraz wprowadzenie usprawnień. Poprawiono również stanowisko pracy operatora przez zastosowanie metodyki 5S w celu zwiększenia efektywności, ergonomii i bezpieczeństwa. Problem nieplanowanych przestojów rozwiązano dzięki narzędziu TPM i harmonogramowi czynności. Badanie miało na celu nie tylko poprawę wydajności maszyny Biesse Techno Line FDT w przetwórstwie drzewnym, ale również miało pozytywny wpływ na aspekty zrównoważonego rozwoju. Skrócenie czasu przezbrojenia przyczyniło się do redukcji zużycia energii i materiałów oraz ograniczenia odpadów. Dodatkowo poprawa organizacji stanowiska pracy i eliminacja marnotrawstwa przyczyniły się do polepszenia ergonomii, bezpieczeństwa i zdrowia pracowników. Badanie to miało zgodność z koncepcją zrównoważonego rozwoju, dążąc do osiągnięcia efektywności ekonomicznej, minimalizacji wpływu na środowisko i korzyści społecznych.

Słowa kluczowe: zrównoważony rozwój, lean management, TPM, lean manufacturing, technika SMED, metodyka 5S