Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Research of Changeover Process in Automotive Company Using SMED Method

Master's Final Degree Project

Gustas Stupelis

Project author

Assist. Prof. dr. Ingrida Venytė

Supervisor

Kaunas, 2025

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Industrial Engineering and Management (6211EX018)

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Assist. Prof. dr. Ingrida Venytė

Supervisor

Assist. Prof. dr. Laura Gegeckienė

Reviewer

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Task of the Master's Final Degree Project

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1. Title of the Project

Research of Changeover Process in Automotive Company Using SMED Method

(In English)

Keitimo proceso tyrimas automobilių įmonėje naudojant SMED metodą

(In Lithuanian)

2. Aim and Tasks of the Project

Aim: to study changeover process in an automotive company using SMED method.

Tasks:

1. to compare production processes which are applied during products changeover;
2. to choose the most relevant and suitable production management process which ensures smoothest product changeover;
3. to compare the results of product changeover process before and after application of the SMED method for SMT production line;
4. to perform cost effectiveness analysis.

3. Main Requirements and Conditions

5S, Spaghetti Diagram, Poka-Yoke, Kanban, SMED.

4. Additional Requirements for the Project, Report and its Annexes

Not Applicable

Project author	Gustas Stupelis		07-03-2025
	(Name, Surname)	*(Signature)*	*(Date)*
Supervisor	Ingrida Venytė		07-03-2025
	(Name, Surname)	*(Signature)*	*(Date)*
Head of study field programs	Regita Bendikienė		07-03-2025
	(Name, Surname)	*(Signature)*	*(Date)*

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Summary

The LEAN methodology is widely used in various manufacturing enterprises. One of the most competitive industries is automotive. Electronics production is advanced, however, the changeover process between different types of products is time-consuming. 5 LEAN methods were analyzed and described. The 5S method is a practice used to ensure a tidy and clean manufacturing environment. Spaghetti diagrams analyze excessive movements performed during production processes. Poka-Yoke method is used to reduce the possibility of human errors. Kanban raw material scheduling system used to ensure just-in-time production. SMED method LEAN management tool used to reduce duration of the changeover. Changeover is time time-consuming process where excessive movement can cause downtimes which increase production costs. The goals of this research are to compare production processes applied in changeover, choose relevant and suitable production management methods, compare the results of the changeover process before and after the application of the SMED method, and perform cost-effectiveness analysis. Various scientific sources that apply SMED were analyzed. The SMED method has a major impact on different production enterprises affecting cost saving, waste reduction, and improved productivity. The methodology was created according to examples applied in manufacturing companies. The changeover process was analyzed in an automotive electronics company that produces parts for major players in the market. Changeovers were analyzed in two production Surface Mount Technology lines using SMED methodology. Both SMT production lines were compared, and it was concluded that the same solutions were to improve the changeover process. The solutions were proposed by applying 5S and spaghetti diagram methods. Applied SMED method and solutions reduced changeover time resulting in increased productivity and cost savings. SMED method reduces downtimes and improves changeover efficiency and flexibility.

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Santrauka

LEAN metodika plačiai taikoma įvairiose gamybos įmonėse. Viena iš konkurencingiausių pramonės šakų yra automobilių pramonė. Šioje pramonės šakoje elektronikos gamyba yra pažangi, tačiau keitimo tarp skirtingų gaminių tipų procesas užima daug laiko. Projekte išanalizuoti ir aprašyti 5 LEAN metodai. 5S metodas – tai praktika, naudojama siekiant užtikrinti tvarkingą ir švarią gamybos aplinką. Spagečių diagramose analizuojami pernelyg dideli judesiai, atliekami gamybos procesų metu. Poka-Yoke metodas naudojamas siekiant sumažinti žmogiškųjų klaidų galimybę. „Kanban“ žaliavų planavimo sistema, naudojama siekiant užtikrinti gamybą tinkamu laiku. SMED metodo LEAN valdymo priemonė, naudojama pakeitimo trukmei sutrumpinti. Keitimas yra daug laiko reikalaujantis procesas, kai per didelis judėjimas gali sukelti prastovų, o tai padidina gamybos sąnaudas. Šio tyrimo tikslas – palyginti pakeitimo metu taikomus gamybos procesus, pasirinkti tinkamą gamybos valdymo metodą, palyginti pakeitimo proceso rezultatus prieš ir po SMED metodo taikymo, atlikti kaštų efektyvumo analizę. Buvo išanalizuoti įvairūs moksliniai šaltiniai, taikantys SMED. SMED metodas turi didelę įtaką įvairiose gamybos įmonėse, turinčios įtakos sąnaudų taupymui, atliekų mažinimui ir produktyvumo gerinimui. Metodika sukurta pagal gamybos įmonėse taikomus pavyzdžius. Keitimo procesas buvo analizuojamas automobilių elektronikos įmonėje, gaminančioje dalis pagrindiniams rinkos žaidėjams. Pakeitimai buvo analizuojami dviejose gamybinėse *Surface Mount Technology* linijose naudojant SMED metodiką. Palygintos abi SMT gamybos linijos ir prieita prie išvados, kad keitimo procesui pagerinti taikyti tie patys sprendimai. Siūlomi sprendimai taikant 5S ir spagečių diagramos metodus. Taikytas SMED metodas ir sprendimai sutrumpino perjungimo laiką, todėl padidėjo našumas ir sutaupoma sąnaudų. SMED metodas sumažina prastovų laiką ir pagerina perjungimo efektyvumą bei lankstumą.

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Abbreviations:

SMED – Single Minute Exchange of Dies
SMT – Surface Mount Technology

Introduction

Different industrial enterprises produce various finished products. To ensure and keep a high level of production, industrial companies must implement and rely on the LEAN methodology. Different companies, despite what kind of finished products they manufacture, produce products that are manufactured according to the company's needs and implemented standards. One of the industrial enterprises is an automotive industry company. The automotive industry is highly competitive because the market size is calculated around 279.93 billion in 2024. For automotive companies, it is important to apply various production processes and produce according to the implemented production processes, to ensure the best quality of the final product parameters. Companies that rely on implemented processes and adhere to give more satisfaction to customers and receive trust from the customer's side. Automotive manufacturing companies produce different finished electronic products for various final customers and the main idea and focus should be concentrated on how to reduce the changeover time during production. Changeover time indicates how long it takes to change from one producing product to another. Changeover time should be reduced to a single-digit minute with the SMED (Single Minute Exchange of Dies) method application support. This work describes and analyses the main method – SMED, which is mostly applied during the changeover. The main principles, application areas, and advantages brought by the SMED application are indicated in this paper. In addition, the SMED method will be applied to an SMT (Surface Mount Technology) production line and investigation and solutions on how the SMED method can reduce changeover time will be indicated. A cost-effective analysis will be calculated and indicate how much the cost can be reduced by a successful SMED application. This paperwork also mentions other production processes that ensure smoother changeover and SMED application. 5S method, spaghetti diagram, Poka-Yoke, and Kanban – those are methods that allow the better application of the main method – SMED. The 5S method ensures a clean, tidy, and safe working environment. It helps to determine working area standards and ensures that all employees follow the standard. During the SMED application 5S method helps now when tools or materials need to be found, it will be easy to do it if it is placed in their belonging place and marked. A spaghetti diagram assists when trying to understand walking activity during the changeover and how it can be reduced. A spaghetti diagram is one of the processes that can help reduce walking time. The Poka-Yoke method ensures that human errors are avoided during the changeover and the probability of the operator performing the changeover faster increases due to the avoidance of repetitive errors. The Kanban method is the last method that can be used in parallel with the SMED application. It provides information on cards about how the changeover process will work. The digital Kanban system can have its benefits by providing all the needed information in a digital space. Four indicated production processes have a direct impact on changeover time. Changeover analysis is relevant for each highly demanded company because this could be the key to production flexibility and performance. The shorter the changeover time, the better the efficiency results are achieved. Production costs and downtime reduction are the main aspects of staying in the market. The SMED method is relevant to reducing the changeover time during production, which seeks to optimize the efficiency of the production line and reduce downtime. The novelty of the changeover analysis is related to the innovative quality management methods and Industry 4.0 goals.

Aim: to study changeover process in an automotive company using SMED method.
Tasks:
1. to compare production processes which are applied during products changeover;

2. to choose the most relevant and suitable production management process which ensures smoothest product changeover;
3. to compare result of product changeover process before and after application of the SMED method for SMT production line;
4. to perform cost effectiveness analysis.

Hypothesis: SMED method reduces downtimes and improves changeover process efficiency and flexibility.

1. Applied Production Processes During Change-Over

Nowadays, many different production processes are used that help optimize and more effectively manage production parameters and ensure smoother production. This part of the final master's thesis reviews the manufacturing processes that allow for the smoothest possible replacement of one product for another during production, called the change-over or setup process. Five of the main production quality management methods are reviewed and one process is identified that allows for the smoothest changeover in production.

1.1. 5S Method

The 5S method is one of the LEAN manufacturing methodology topics. The main goal of the 5S method is to reduce or eliminate as much waste as possible. The concept of the 5S method is found not only in the industrial sector but also in medicine, administration, or any other industry. By applying the 5S solution, the best and simplest methods for employees are found to keep the workplace tidy and clear. 5S methods include five main activities such as sorting, setting in order, shining, standardising, and sustaining. All rules that start with “S” help to improve productivity and reduce time which is related to searching for needed tools. 5S method implementation does not guarantee company success or good profit. For the companies, it is also important to seek continuous development of the 5S method and consistent adherence [1–3]. Phases of how to implement the 5S method are indicated below:

The first word and the first S of the 5S method are sort. With the sort step, the process tries to eliminate unnecessary items from production that do not add any extra value to the production and the finished product and are easy to eliminate from the working area. A system that is used to keep material in the right spot and positions in manufacturing enterprises is called “Sort”. Due to rarely being used materials or equipment in the workplace, the workplace can be demolished, and labour efficiency reduces each time. The sorting step is one of the best and most effective ways to transform the working area into a clean and tidy environment. In sorting the following criteria can be included [1–3]:

1. What needs to be done to achieve the most efficient way?
2. When is it necessary to reach the most efficient way?

Two questions for the implementation phase can be included:

1. Necessary and unnecessary tools, materials, and equipment have to be determined;
2. Decision to locate unnecessary tools, materials, and equipment. Otherwise, it has to be removed or disposed [1–3].

The second letter of the 5S method indicates set-in-order action. It indicates that unorganized items must be selected and placed where they fit the best, avoiding any kind of congestion. One of the main steps of this process phase is to use as much visual approach as possible, to avoid time loss during search and proof of mistakes. The basic guidelines of applying set in order phase are indicated below [1–3]:

1. Collect and analyze previous years’ data to understand and establish sorting relationships;
2. Related items have to be located together;
3. In separate rows, different items need to be stored;

4. Item cannot be stacked, racked, or shelved together;
5. Clear and visible labeling needs to be attached to each item and storage unit.

Labelling is needed for other people who are not production area supervisors or workers. The main benefit is that the search decreases a lot. Labelling should be done in the native language of the country in which the company is operating. Labelling in the native language is important for employees who have lower qualifications and issues with foreign languages. To avoid injuries related to muscles and bones by lifting and carrying boxes, trays, etc., employees need to follow ergonomic standards [1–3].

The third letter of the 5S method indicates the shine step. Once the unnecessary items, tools, or equipment are eliminated and the needed and necessary items are sorted and set in order, the next step indicates that the cleaning needs to be performed. This step's main purpose is to eliminate and remove the root cause of the waste, dirt, and damage. In this step, all the company employees must be included, because they will do the cleaning step, and they need to understand how often it has to be done. Dirt, waste, and pollution can cause poor production, dirty working areas, or even accidents during production on the shop floor. The working area should be cleaned regularly. After the usage of each tool or material, everything has to be moved back to its original place. The cleaning schedule has to be done together with the tasks that have to be done by the whole personnel. Periods have to be decided when the tools or equipment will be maintained and cleaned. The next question that has to be taken into consideration is whether the dirty equipment can cause hazards for employees. Tools need to be cleaned from time to time, proper training should be provided, to increase employee's information level about how to maintain clean resources and prevent damage to resources [1–3].

The fourth step of the 5S method is standardization. After cleaning the working area, it is important to maintain the working area as it was. That is why the company develops and creates standardized processes, rules, and expectations for continuous maintenance in the whole company area. Standardization includes the development of visual guidelines on how to keep the working environment clean and tidy. It is a method to create consistency. Companies seek to ensure that consistency and cleanliness are maintained at the highest level and standardized. Standards should be easy to understand, communicative, and with a good description. In the planning and transformation stage, all information has to be communicated to all employees, including management. Check sheets should be implemented and the method which is used in the planning stage needs to be documented. The shop floor manager, supervisors, and management should be involved in check sheet activities. Everyone can easily see what is needed to perform and what is required to perform the tasks. The plant should also create procedures for daily check sheets in the workplace. The check sheet should indicate that the employees follow the requirements of the previously mentioned 3S methods [1–3].

The last 5S method letter indicates sustain. This step defines how things should be done in the right way. This encourages employees to act positively. Lastly, fifth S is important to correctly understand and implement because it includes all active employees' behaviour at all company levels. This function is important also to keep the continuous employee's routine. In this, it is important to keep self-discipline, and it should be maintained all the time. After the application of the correct 5S method, it is crucial to have the ability to maintain it. The previous four 5S phases give strong, easily visible, and easily quantified effects. People who perform to maintain 5S are one of the most important factors. This is one of the most difficult steps which have to be performed and applied. Supervisors and team members work together and seek the 5S goals. 5S includes training and seeks that employees would perform the simplest tasks correctly. After the 5S method integration in the company, management should train employees on the 5S method approach daily. Every company employee should understand the importance of health, safety, order, and cleanliness, and the most important thing is that they should think about the necessary effort that needs to be added to ensure the best quality in the production area. For the successful implementation of 5S in their working area, employees should be rewarded. Rewarding employees will increase their interest, morale, and commitment to implementing the 5S method. Continuous improvement allows the employees to have a clear understanding, correct structure and processes, and the ability to adapt to 5S. Employees' morale and participation in performing 5S should be at a high level. It is important not to forget the previous 4S letters and keep them maintained. Fig. 1 indicates all five S letters and how in order they should be applied in the working area [1–3].

Fig. 1. 5S method in order [4]

Seeking to increase productivity and reduce employee absenteeism, it is important to implement a clean and hygienic work environment not only in the shop floor area but also in the office workplace. 5S implementation has a positive impact and benefits focused on companies' improvements and waste elimination [1–3]:

- Time required for tool changes is reduced;
- Product quality increased;
- Errors number decreases, which results in more savings;
- Employee satisfaction and morale is increased;
- Productivity increases;
- Ensuring a stable supply chain to the final customer;
- Stable employee safety;
- Customer's trust increases in supplier.

1.2. Spaghetti Diagram

A spaghetti diagram is a method to watch an object's movement in a system or an area with the help of a simple line. The moving object could be employees, production operators, or even material. The system in which objects can move can be a shop floor area, building, facilities, etc. The diagram is called spaghetti because the movement of the object can be chaotic. Fig. 2 indicates an example of a spaghetti diagram [5–7].

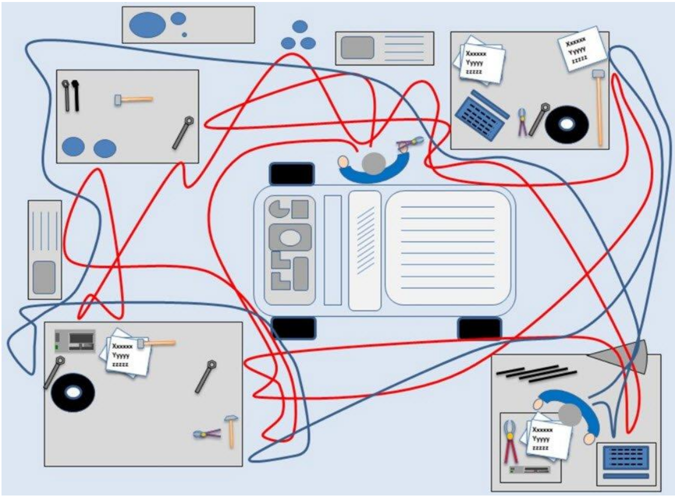

Fig. 2. Example of a spaghetti diagram [8]

Using a spaghetti diagram, the movement of products, workers, and semi-finished goods can be tracked. Different colors can be used to more clearly understand how different products move, for example, red color for the products, and blue color for the employees. With the spaghetti diagram, movement can be also tracked at different times. After spaghetti analysis, can be recognized movement length, number of movements, crossing movements, and movement characteristics according to chosen classification. After the application of the spaghetti diagram, companies can identify inefficient or inappropriate movement and ineffective zones. It helps to eliminate working staff, organize the work, and change the workstation layout [5–7].

The spaghetti diagram is mostly used in manufacturing companies, which streamline shop floor processes. Spaghetti diagrams consist of lines like kinds of spaghetti, which indicates operator movement in the shop floor area during the process. The diagram can indicate and show inefficiency, which can be improved and make workflow better. Cycle time in the manufacturing company is important, each factory's operations and process have its own cycle time. By reducing operation cycle time, effectiveness can be increased. The spaghetti diagram together with measurements helps to analyze which operations and be improved by reducing cycle time. Making a spaghetti diagram is kind of an easy thing. Results can often surprise because it is natural that for management and operators, it is hard to see daily processes and operations inefficiency. Spaghetti diagrams allow management to see the floor in another way – chaotic activity can be seen clearly, in concrete form, which can make analysis clear. Below are indicated the main steps of how a spaghetti diagram can be drawn to see more clearly the view of inefficient shopfloor activities [5–7].

1. Mapping area which has to be analyzed – spaghetti diagram is easy to make. Theoretically, it can be done using a pencil and a napkin. Working with a pencil and a napkin can be messy, so it is recommended to use a tablet, so the view of the spaghetti diagram can be streamlined and nice. In the first of the spaghetti diagram, a clear view of the place, which will be analyzed, has to be done. Make sure that all physical objects are included in the plan. The spaghetti diagram should indicate all plans with objects included in your shop floor area.

2. Number everything that is included in the process – when all shopfloors are mapped neatly, all processes that need to be analyzed should be marked. It can be used for equipment, also extra spaces, to which the operator can go, to get spare parts or needed tools.
3. Drawing lines for every movement – when the map is created clearly and enumerated correctly, line drawing can start. There are several ways to do that – The first way is to draw a line which intersects each number. The second way is to draw separate lines in a different color. It will be useful when doing a quantitative analysis. It helps to present a measurement of movement for a specific operation.
4. Measuring distance and time – to make a detailed analysis, distance and time measurements of operations have to be done. It can be done using a chronometer or measurement wheel. Results can be summed up in a simple diagram. Measuring the overall transit time and distance of the entire process and separate operations gives a perspective of all spaghetti diagrams. Before going to another step, consideration has to be taken that the spaghetti diagram should be done more than one time with different operators to receive more precise data. It can be that one operator made just one mistake. If you have a sample of a primary spaghetti diagram, you can compare it with all other diagrams.
5. Analysis of the results – after the creation of the spaghetti diagram, can be sawn, what kind of adjustments can be made to improve the process. The great thing is that a spaghetti diagram is good for doing comparisons with other results. Implemented changes in the shop floor area can be compared with the result of future spaghetti diagrams. If the new spaghetti diagram has fewer kinds of spaghetti, it indicates that the efforts were successful [5–7].

A spaghetti diagram can help every company to streamline each process via process mapping. The main benefits that can be brought by implementing the spaghetti diagram in the manufacturing company [5–7]:

1. Identification of inefficiencies – easy way to see the most problematic areas and pain points, With the creation of work layout and plans creation inefficiencies can be eliminated;
2. Creation of an effective flow – reduce wasted time and delays, which can be caused by operators movements from one location to another location to get their work done;
3. Faster production – improved process layout, assures that the operators make their job faster. This makes the production more faster;
4. Optimization of delivery times – identify points, on which delivery time can be reduced, for example – reduced distance from one working station to another;
5. Clear directions – setting a working path, reduces confusion among the operators;
6. Fatigue reduction – it is a benefit for employees if the reduction of necessary movement and physical activity is reduced;
7. Saving money and time - all the above–mentioned benefits impact faster production and delivery time and reduce time and money that would be spent on a slower and more chaotic process [5–7].

Essentially, the spaghetti diagram method allows you to notice chaotic operator activity and thus ensure that the operator's activity is performed as quickly and efficiently as possible [5–7].

1.3. Poka-Yoke Concept

Poka-Yoke is one of the quality management concepts, which prevents from arising human fault during production, which was introduced by a Japanese industrial engineer. Poka-Yoke deals with mistake proof or proof of error as originally sounds yokeru (avoiding) and poka (mistakes). Mistakes or errors can arise when doing any kind of job, for example, missing operation, working not according to protocol, using wrong tools, missing or using parts with defects, or using inappropriate tools for measuring [9].

The philosophy that is the main core of the poka-yoke concept is respecting human rights and most importantly respecting intelligence. Performing operations that depend on watchfulness and memory, poka-yoke can reduce time to release the worker's mind for creative operations and increase their value. In each product's life cycle and each process and its operations there is the probability of errors arising. Due to errors finished products can have defects and the customer cannot be satisfied. Poka-yoke is a method, which is based on convenience, which means that it is not acceptable to produce finished products if they even have a small number of defects. For companies, the production of finished products with a 0 percentage of scrap rate is not only the biggest challenge, but also a necessity. The Poka-yoke method is a simple technique that ensures production with a 0 per cent scrap rate. Fig. 3 indicates an example of how poka-yoke most often works out to avoid human errors [9, 10].

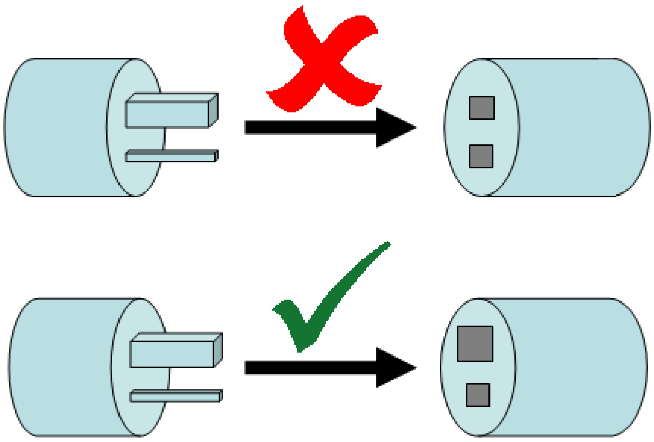

Fig. 3. Poka-Yoke concept example [11]

The poka-yoke technique can be applied to prevent causes, that can cause in the future arising problems, or also do a cheap control, to know if to keep or reject a finished product. There is not always a probability to eliminate all errors 100 per cent, in those cases poka-yoke method task is to detect problems as fast as possible. By analyzing the process of how the error occurs, it can be noted that between mistakes that arise because of the defect, there is also a probability that could happen is observation mistake and its correctives [12].

The Poka-yoke method can be categorized into two systems, which are related to regulatory functions and setting functions. Two poka-yoke systems that are related to regulatory functions are related to control methods and warning methods. Control methods stop machines or operations when abnormalities are identified. Warning methods warn operators through warning signals, for example – a buzzer or light, when abnormalities arise, but the process is not stopped. Based on what kind of types are in the poka-yoke method, functions can be divided into three main methods – contact method, fixed-value method, and motion step method. Using contact methods, established shapes or dimensions of the product, based on their contact between the sensor and the product. Applying the fixed-value method, abnormalities can be detected by checking if the motion number was repeated, according to the established motion number. Applying the motion step method, deviations are established by checking if standard movement is performed according to the work standards [12, 13].

There are a lot of benefits that can be brought by implementing the poka-yoke method, but the main benefits of the poka-yoke method, which can increase the efficiency of operations and production:

- Improved productivity – it is easily understandable for operators' need for poka-yoke and how it works in the company. The concept of poka-yoke as a method is inexpensive to implement and is a smart production method, which can easily improve productivity in automotive manufacturing companies;
- Proper detection of errors – the poka-yoke method can be easily used to avoid unnecessary and unexpected problems and coordinate operators on how to eliminate production issues. The Poka-yoke method does not let move to another step if the error occurred in the previous step. If the production error can be detected in an early-stage phase, it can save a lot of time and money;
- Quality improvements – daily operators do a lot of repetitive work, which gives them opportunities to improve quality processes through poka-yoke. Furthermore, a good quality product means reduced processing and product costs;
- Improved health and safety – working full shifts with automated equipment can be risky. Poka-Yoke ensures that any safety precautions will be not avoided;
- Waste reduction – due to well-designed processes, which help to reduce mistakes and the possibility of quickly seeing all errors, waste reduction is inevitable. Poka-yoke achieves this goal because company processes include quality, which reduces the need for rework which reduces defects [10, 13].

In implementing the poka-yoke method in an industrial company, the main goal is to help operators avoid operational failures, for example, choosing the wrong tool or part for the assembly, even if the procedures are correctly indicated in the documentation. The operator can be distracted, forgetful, or maybe he had inadequate training, poka-yoke will ensure that the operator will avoid basic failures in the shopfloor area [9, 10, 13].

1.4. Kanban Method

Kanban is one of the pull system tools, which manages material flow from one process to another, using the Kanban card or digital signal. Each Kanban signal is a specific manufacturing order for production demand. It activates the performance of the work when it is only necessary. It ensures that the level will stay stable in the process flow. Also, the Kanban method can be used to efficiently communicate with internal and external operations like – production schedule, delivery time, and information about raw materials [15–17].

The traditional Kanban system is established on Kanban cards. Each card is related to the specific production process part. In the card, there is all the needed information and details, which is needed for each process step. The Kanban card system is easy to implement if there are low costs, which can ensure control of the continuous flow of materials and production. On the other hand, the Kanban system has some limitations, due to unproductive work, because it is possible to manipulate the Kanban cards. Kanban card movement always has unevenness, because cards are not moved out at the same time when raw materials are consumed. Increasing production operation pace and producing in bigger batches, evenly increases card movement number – in that case, most often cards are misplaced, which can cause problems with just-in-time production. Sudden demand changes, frequently decreasing or increasing, can also cause damage to the traditional Kanban system. It requires adjusting usable Kanban card numbers and updating information that is used on the Kanban cards. Not for all companies, the Kanban card system is suitable. The Kanban card system is not suitable for companies that have deviations in demand from the customer side, have poor quality production processes, or even if companies have a wide product portfolio. In table 1, the main Kanban benefits are indicated [15–17]. The main benefits of the Kanban system are singled out below:

- Better visibility – visualization is an important practice of the Kanban system and the most reckon way is a Kanban board. Using Kanban board it is easy to see how the tasks are moving. Due to visual presence, it is easy to see obstacles and how they form;
- Improved efficiency – the best benefit of a Kanban system is improved flow efficiency. Visualizing your process can be seen as an inefficient area. Each obstacle removed makes your process smoother and more efficient;
- Increased productivity - the Kanban system increases productivity by focusing on starting work to the end of the work;
- Reduced waste – waste reduction is one of the LEAN management focuses. Waste can be defined as an action that requires using resources to add extra value to the finished product. Kanban drastically reduces waste by reducing waiting time;
- Flexibility – Kanban offers solutions to focus on backlog management, which helps teams to be more self-managed. Using Kanban gives teams the flexibility to create a sustainable competitive advantage.

In the 4.0 industry, electronic or digital Kanban systems are used, which are based on a digital signal, which can offer more advantages than a regular Kanban card system. The electronic Kanban system, also known as e-Kanban, is a signal-based system, which uses different technologies, like bar codes, RFID (radio frequency identification), and electronic reports. All mentioned automated systems activate material flow in the production or inside equipment. Using the technologies mentioned, the Kanban system can be more convenient and reduce errors that occur on the Kanban card system. This kind of Kanban system can be integrated into companies' enterprise resource planning system, which contains all companies' information in one database. An electronic Kanban system is like a command panel, which helps to see real-time demand signals and provides each system working station status overview. All information which is related to transactions is automatically collected and analyzed in the different stages of production, which can help to control and make decisions, which are closely related to the size batches of the production. This kind of information can also indicate the movement of the product in each manufacturing stage [16, 17].

The e-Kanban system supports the implementation of a pull system in the production area, in which traditional Kanban systems would face difficulties. Digital Kanban system can be used with production flow, which often fluctuates according to customer demands. Using Kanban, each batch location and size and know, and Kanban card substitution happens automatically in the computerized system. Kanban digital cards act as a communication pattern between suppliers and customers. Quality problems and equipment failures are minimized to a minimum. Also, the Kanban system can create visibility and improve the manufacturing of finished products. In addition, there are still areas where the old-school Kanban system can be superior, it only happens when in the ERP system there is no production information [16, 17].

According to the description above about the Kanban system, the identification of four main subsystems of Kanban can be described below, and Fig. 4 is a visual representation:

- Operator – the main person in the process. The operator supervises how the current Kanban system is functioning;
- Informational system – Kanban signal can be Kanban card or Kanban digital signal. Kanban card or signal does the performance of two jobs, on one hand, it allows for customer workspace to receive information about products and on the other hand, it orders a workspace for a supplier. Kanban board can be used to request production priorities and receive information about work in progress level;
- Material flow system – product flow only has one direction. Produced products move from supplier workspace to customer workspace, that's how products travel from supplier to customer. Otherwise, packaging material moves in the opposite direction, it moves from customer to supplier. Packaging material is used to deliver materials from one place to another in specific packaging;
- Machine – Kanban signal allows communication between nearby working stations, which are connected through material handling equipment [16, 17].

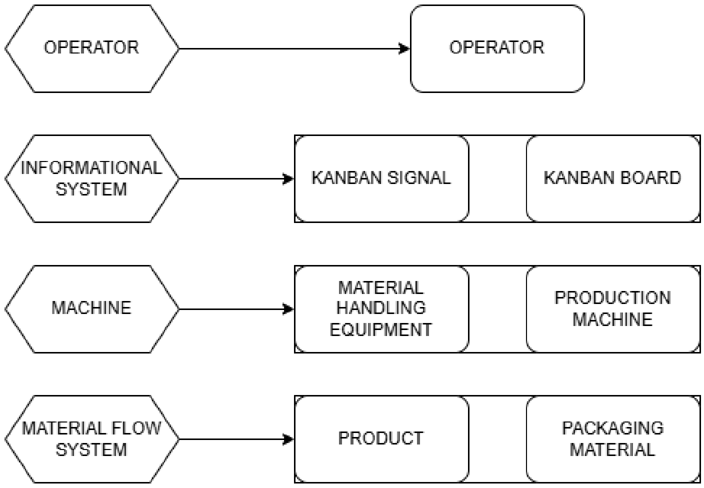

Fig. 4. Responsibilities in Kanban [17]

Fig. 4 indicates that the main person in the Kanban system is the operator. The operator visualizes the priority of order and work-in-progress product on the Kanban board. The operator is also responsible for reading the Kanban system and work order transmission to the machine, which is responsible for an extra value added to the product. Using the Kanban card system, the operator is responsible for transfer from supplier/customer workspace. In some cases, the operator will also increase the value of the product by transferring packaging material or materials [16, 17].

1.5. SMED Method

SMED method is one of many LEAN production methods, which can reduce can eliminate waste in the production. It helps rapidly convert the manufacturing process from running the current product and start running the next product. This method is great when seeking to reduce production lot size and improve product flow. The phrase, which means single minute does not mean that all setup or change-over times should be one minute or less; it indicates that the setup or changeover time should be reduced to a single digit minute, which suggests that in the best scenario, it should happen in less than ten minutes. In the beginning, SMED was created to improve die press and machine tool setups, but the main principles of SMED can be applied to all types of processes. The setup operation can be defined as preparation before or after each production while preparing to produce any other finished product. Setup operations can be divided into two segments: internal and external. Internal means that all operations and activities can be done only when the equipment is not running. External means that all operations and activities can be performed while the equipment is running and producing. These operations can be performed before or after the machine shuts down. The three main activities of the SMED method [18, 19]:

1. Separating internal and external activities;
2. Converting as many internal activities as possible to external activities;
3. Making all activities as simple as possible [18, 19].

The most important step of the SMED method is to separate internal, which can only be performed while equipment is shut down, and external activities which can be performed while equipment is still running. The SMED method can be applied in three stages [20, 21].

1. First stage – all operations that can be adjusted are performed after completing the previous production. Activity, which seeks to correct previous situations and reduce setup time should be separated into online (internal) and offline (external) manufacturing activities. Manufacturing activity in the offline stage can be performed while producing the previous product. On the other hand, online manufacturing activity can only be performed after the production of the previous product is produced. The first stage of the SMED method indicates that the setup time is only impacted by process time. Knowing and understanding how and who is impacting the setup can reduce change-over time from 30 to 50 per cent.

2. Second stage – mostly focuses on activities that are related to internal activities. As an example, a cavity change can be performed only after production. The cavity changes to a new one, only being replaced after finishing producing the last product with a specific cavity. Mostly, we should focus efforts on how to convert as many internal activities as possible into external activities. Those efforts can reduce changeover time to 90 per cent by only making initial changes.

3. Third stage – improvements and arrangements can be made, only after analyzing internal and external activities to the smallest details. The second and third stages can be performed in parallel. In this case, the second and third stages were analyzed separately to indicate their meaning and benefits. SMED ensures that the changeover time can be reduced due to the rapid production of several different products [20, 21].

The SMED method seeks to optimize equipment utilization, by enabling production in small lot sizes, reducing the production time, and reducing the time on which equipment does not produce and perform. It helps to shorten the preparation time of the equipment, reduce stocks, and shorten machine adjustment time. The main benefits of implementing the SMED method are indicated below:

- By reducing change-over time, increases the ability to produce in smaller batches;
- Flexible production ensures on-time delivery capability;
- Due to production in smaller batches, it reduces inventory;
- Lower operational capital is needed;
- Finished products of better quality;
- The stacking area is more regular;
- Product variety and labour-saving;
- Increased production due to just-in-time production [20, 21].

Three main reasons can be indicated why the changeover or setup time should be reduced in manufacturing companies that produce more than one finished product and have more than one manufacturing production line.

- Flexibility – the company should always react quickly to changing customer demands. Due to the production of more than one product, it is hard to be flexible if the changeover is not highly reduced;
- Bottlenecks capacity – due to different bottlenecks in the production, every minute of the change-over is important. Set-up time should be reduced, so that the production capacity can increase;

Cost minimization – production costs are directly related to the equipment downtime and performance. With reduced setup time, equipment faces less downtime, which can reduce production costs a lot [20, 21].

1.6. Comparison of Analyzed Methods

LEAN methodology has a lot of advantages, especially for manufacturing companies. However, selecting suitable methods in different situations is important to reach the best results. Summary of analyzed methodologies presented in Table 1:

Table 1. Comparison of LEAN methods

LEAN Method	**Purpose**	**Application**	**Disadvantages**
5S	Tidiness of workplace.	Creation of a clean, organized, and tidy workplace.	Do not have a direct impact on production efficiency.
Spaghetti Diagram	Visualization of production process flow.	Optimization of employees and material workflow.	The main focus is on excess movement, not time reduction.
Poka-Yoke	Prevention of human errors	Reduction of human errors and improvement of operations and product quality.	Prevents production from human errors but does not directly improve the time reduction of non-value-added processes.
Kanban	Control of inventory in stock.	Overstocks and overproduction reduction, just-in-time maintenance.	It is not related to time reduction, only related to overstock.
SMED	Change overtime reduction.	Increase efficiency of changeover between different products.	Requires detailed analysis of the process.

In a lot of cases, the changeover between different product production shop orders is the most problematic and time-consuming process, especially when the market demands the company's flexibility. SMED methodology is used to analyze changeover and production processes because it represents the clearest view of excess processes and time consumption. Identification of time consumption view lets analysts set goals for the related process which helps to reduce non-value added times. Afterward, all other LEAN methods can be used to improve current production and reach efficiency goals.

Changeover – is a time which is needed to change producing product by another in the production line. In general, changeover time also includes the time on which the first good part comes out of the production line. If the first good piece is produced without any additional changes, the first produced piece time is considered as production time. Short changeover time conditions ensure short lead times for the product. The long period of the changeover can cause the following problems [31, 32]:

- Increase waiting time for further productions;
- Wasting equipment capacities for production, because of a long changeover [31, 32];

On the other hand, companies also face high costs of the changeover process which leads to three essential issues:

- Large production quantities are required in production, which prevents production from making fast reactions to frequently deviating customer demands;
- Due to large batches of production, lead to overstock and unfinished production;
- Large inventory requires a lot of space in the production and in the warehouse, for people, storage handling equipment, and transport – which increases companies' costs [31, 32].

The main methodology of the SMED method is to understand that there are two main activities during the changeover. It is divided into internal activity – which is performed when the equipment is shut down and external activity, which is performed or can be done while the equipment is still running [31, 32].

Separation of the activities allows more effective distribution of work and reduces downtime of the equipment. It is a fast and effective way to convert production from producing one product to production of another product. This change ensures that production can produce products in small lot sizes and improve general flow. The phrase "single minute exchange of dies" does not indicate that all changeovers should be reduced to less than a minute. It indicates that it should take less than ten minutes. During the changeover process analysis, the SMED method also focuses on how to eliminate or convert internal activities to external ones. Successful internal activities conversion to external minimizes costs and waste. The validity of the SMED method and procedures can be verified by application in an automotive company, metal manufacturing company, or any other manufacturing company that produces more than one finished product, and the changeover time reduction has a huge impact. With minimal investments, a changeover time can be reduced and have a huge impact on company sales. As well the question and concern of operator safety and ergonomics can be noted [31, 32].

Setup time can be defined as the time that is needed to prepare necessary resources, for example, equipment, materials, or preparation for the operator before the changeover process. The cost of setting up is like any other cost which is needed to execute the task. As a LEAN philosophy method, the SMED process has to ensure quality, efficiency, and effectiveness of the continuous improvements made to single minute exchange of dies. The changeover process of the SMED application method is as follows [31, 32]:

- Compliance with current methodology. The current changeover or setup time activities are recorded. It covers the whole changeover process when it is applied, from producing one product to performing substitution for another product production;
- Separation of internal and external activities. Internal activities can be performed when the process is stopped, and external activities can be performed when the last production is produced or even at the start of further production;

- Streamlining the process of changeover. Each SMED method application and modification should be monitored and expect time changes during the changeover. To reach the best optimal time and reduce changeover time to less than ten minutes, it will be needed to perform more than one changeover. Another aspect is that to reduce changeover time to less than ten minutes, more than one solution or idea must be found and applied;
- Continuous training. After the first successful application of the SMED method and reduction of changeover time to less than ten minutes, proper training for the operators must be performed, so they can understand how properly the changeover should be applied. Training should be conducted by the person who applied the SMED method and found solutions to how to reduce time changeover [31, 32].

In general, to properly perform changeover and reduce total changeover time to single minute digit time, all changeover processes must be monitored from the beginning. To keep a stable changeover time each month, the changeover process should be inspected [31, 32].

1.7. Chapter Summary

In this chapter, the situation analysis of the five main LEAN management methods was analyzed. Five methods were chosen because they mostly help while performing a changeover or preparing equipment for different product production after previous product production. The 5S method ensures that the working environment will be clean and tidy, and all needed tools for changeover will be easy to find. The spaghetti diagram indicates how the movement is performed during a changeover and helps to understand how the walking activities can be reduced. The poka-yoke method, as indicated, prevents human errors and ensures that the change-over or any other activity by the operator should be performed correctly. The Kanban method indicates what kind of steps should be performed not only during production but also by ordering materials for future productions, which can reduce preparation for production time. Finally, the SMED method is one of the most relevant methods that can reduce changeover time and save money for the company. Analysis of the changeover based on the SMED method is easy, but it takes doing video analysis, separating internal and external activities, and trying to reduce the total time of changeover. The SMED method will be chosen to conduct practical research in this work.

2. Methodology of SMED Method

The most suitable method for a changeover process is the SMED method. The SMED method can be applied and used basically in every industrial company, starting from the medicine industry and ending with automotive. In this work, the SMED method will be applied in an automotive company for a chosen line. The SMED method can analyze the changeover process and after application of the SMED method, it can reduce the total time of the changeover and ensure that the changeover will be performed as smoothly as possible. In this case, the SMT (Surface Mount Technology) production line was chosen, to which will be applied SMED method to analyze changeover process. The methodology of the chosen method and production line are described more deeply and clearly in this chapter.

2.1. Surface Mount Technology Production Line

Surface mount technology is also known as an SMT production line. SMT production lines are often used in automotive manufacturing companies, which produce electronic components as a finished product, or products, that will be assembled into final products in upcoming production stations. Surface mount technology is a process during which electronic components are mounted on the surface of a printed circuit board. Electronic components are specifically produced and created to be soldered to printed circuit boards. There are a lot of positions on how and where the electronic components can be placed on the board. The equipment software code also indicates where and how electronic components should be positioned. Electronic components can be capacitors, resistors, integrated circuits, etc. The simplest description of the production line working principle can be described in four steps [22]:

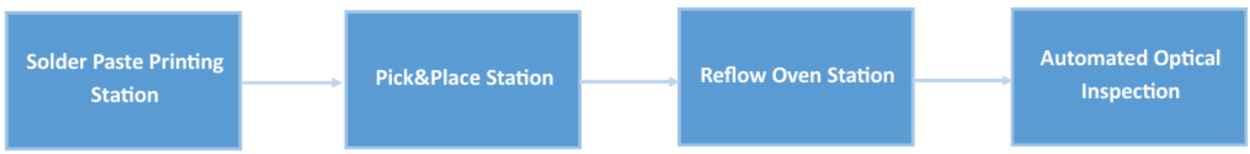

Fig. 5. SMT production line working principle [22]

To ensure that production produces parts of good quality, a visual check of raw materials should be done before production. It can be done by the quality inspector who is responsible for checking if the mentioned parts are capable of use in production [22].

In the first step of production, in the solder paste printing station, the solder paste is printed by a machine to cover all the areas where the components need to be soldered. First, the solder paste is applied through a stencil that is extruded according to the shapes of the PCB (Printer circuit board) as presented in Fig. 6. Solder paste is made of flux and tin and is used to connect SMT components to the PCB with solder paste. During the process of applying solder paste to the PCB board, each part must be coated with the correct amount of solder paste. If all the required parts are not coated with the correct amount of solder paste, there may be problems with the electronic components and the PCB connection when the solder paste melts in the reflow oven. After applying the solder paste, the machine performs a visual inspection to see if the solder paste has been applied properly. Fig. 6 indicates how the application of the solder paste on the board is being done [23].

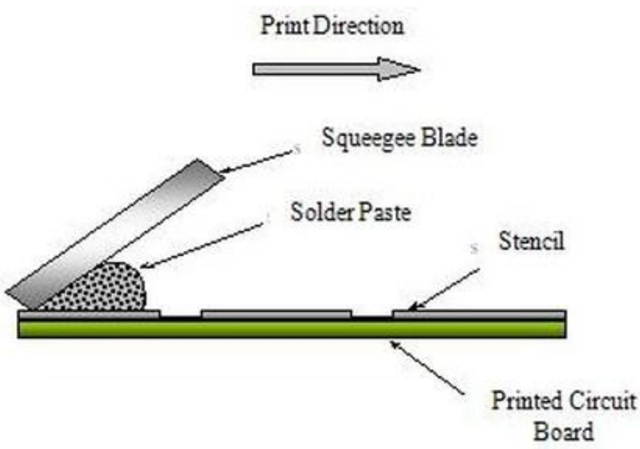

Fig. 6. Application of solder paste on the board example [23]

After visual inspection, in the second step of the production, the board moves to the next SMT line station – assembly of the parts station or in other words can be called a pick-and-place machine. In this station, the components are placed on the board. During production in this stage, all the electronic components that will be placed on the printed circuit board are removed from the reel using a vacuum head needle. The machine then places the components on the board according to the program code. All the required electronic components are placed on the board in the places where they belong, in different positions or angles. After all placement processes, it is checked whether all the components are correctly placed on the mounting board, making sure that all the components will be soldered to the PCB board in a high quality and correct way and that there will be no soldering errors between the components and the board. If production errors related to finished products arise after production, the company will have to redo production or scrap produced products, which will increase the scrap rate, and can cost additional costs. In Fig. 7 it is indicated what the pick-and-place equipment looks like. In this equipment, raw, electronic materials are placed on the printed circuit board [24].

Fig. 7. Pick-and-place equipment [25]

The third step of production is soldering raw materials to printed circuit boards. The equipment which needs to be used in this step is a reflow oven. Fig. 8 indicates a reflow oven, which is used in an automotive and electronic industrial company to produce electronic parts of the finished products [23, 24].

Fig. 8. Reflow oven of SMT production line [26]

In the reflow oven, all electrical solder joints are formed between the components and the PCB. The heat is used to convert the previously applied solder paste into solder. The oven must have the right temperature, as too high a temperature can damage the parts or assembly, and the PCB will not function as intended. If the temperature is too low, the connection may not be established. The machine is placed on a conveyor belt to maintain the exact temperature in the oven. The oven is divided into different heating zones before the PCB passes through the cooling zone. The temperature rises evenly in the various heating zones. The PCB must remain in each zone for the appropriate time. Once all the parts are soldered onto the PCB, the PCB passes through the cooling zone. After the soldering process, all the components are also checked to ensure that they are soldered properly [23, 24].

In the last and finishing step, automated optical inspection is performed. Similar equipment, as indicated in Fig. 9, is used also in electronic industrial companies, to ensure components are properly soldered to PCB. AOI helps more easily identify products that were produced poorly [27].

Fig. 9. AOI inspection [28]

In five small steps how the SMT production line functions can be described. In this work, the SMT production line was chosen as a research object, which will be the SMED method to reduce the changeover time. The SMED method can be applied to all production lines, which produce more than one product. SMT was chosen because it is the start of any production in an automotive company. The main reason why the changeover process should be reduced in the SMT production line is that the SMT crew could more quickly react to deviating customer demands and perform changeover tasks by changing one producing product to another in a production line in the shortest possible time, which also would ensure that further production could keep running smoothly and exports would be stable.

2.2. OEE – Overall Equipment Efficiency

One of the main variables that can indicate how successful the SMED method application was – is OEE, also known as overall equipment efficiency. Manufacturing companies' focus should be oriented towards productivity and efficiency. That's why manufacturing companies need to follow the OEE variable – which is an industry-standard and indicates how efficient production was in a specific period. OEE can help to identify and analyze problems that are related to downtimes of the equipment or why production efficiency is reduced. Identification of bottlenecks, which influence downtimes of the equipment, should be focused on indicators that are related to the system's effectiveness. The main indicator for those identifications is OEE. Overall equipment efficiency consists of three main variables – material availability, performance, which indicates how many total products were produced, and quality rate of produced products. The formula of OEE is indicated below [29]:

$$OEE\ (\%) = A\ x\ P\ x\ Q\ x\ 100\%, \tag{1}$$

where: A is the material availability, P is the performance, Q is the quality rate.

Overall equipment efficiency can be taken into consideration as an excellent indicator, which shows how efficient companies' production is running each day. Equally, OEE is one of the key performance indexes of the equipment or a system. Moreover, the OEE can give insights into how properly the maintenance department maintains the equipment. Relying on this efficiency variable, the focus should be on downtimes and failures. Those two factories have a huge impact on the availability, operational efficiency, and quality of the products. The calculation of availability can be performed by subtracting total production time by downtime and then dividing by total production time, as indicated in formula Eq. 2. Performance can be calculated by dividing the number of products produced during production by total products that had to be produced, as indicated in Eq. 3. Quality of the products calculation can be done by subtracting the number of products produced by defective products and then dividing from a total number of products that were produced, as indicated in Eq. 4.

Below are all three main formulas indicated [29]:

$$Availability = \frac{(Total\ production\ time - Downtime)}{Total\ production\ time}, \tag{2}$$

$$Performance = \frac{Number\ of\ products\ prodcued}{Total\ products\ production}, \tag{3}$$

$$Quality = \frac{(Number\ of\ products\ produced - Defected\ products)}{Number\ of\ products\ produced}, \tag{4}$$

To obtain maximum equipment availability, the focus should be on finding the root causes of equipment downtime and trying to prevent such equipment from occurring as much as possible. Availability variable, in the OEE formula, is the most important, because it also has a huge impact on how many pieces of the product will be produced during one production. Most manufacturing companies need to have implemented production processes. Lack of quality and production processes in the company can lead to the probability of producing products in lower quantity and quality, which leads to a lower equipment performance index. The total number of products produced is an indicator of the performance of the system. It is important to produce the highest quality finished products possible, as malfunctioning equipment can reduce the overall OEE. The SMED method provides a fast changeover, to reduce the total time which is generated by long setups. Long changeover time in the manufacturing companies can be considered as a waste, which causes increasing manufacturing costs. Machine changeover indicates any kind of planned modification – tool change, changing packaging material in a production line, or changing one product to another. Reduced changeover time increases equipment and production system performance. It can significantly increase equipment availability. The SMED idea is a rapid performance of changeover processes, which can reduce lot sizes, improve flow in production, and most importantly increase equipment efficiency and system performance [29]. Three main factors create the biggest impact on losses in production. The three main factors are indicated in Table 2 [30].

Table 2. Factors that create the biggest losses in production [30]

Downtime losses	Time losses and quantity losses	Productivity reductions are caused by the production of defective products
	Setup and adjustment time losses	It can occur when the changeover process is performed improperly
Speed losses	Waste increases and minor stop	Malfunction when the machine faces waste
	Increased speed losses	Difference between product design production speed and real production speed
Quality losses	Increased yield losses	Occurs until equipment stabilizes after early production
	Quality defects and rework	Caused by malfunctioned production equipment

In general, manufacturing companies should keep monitoring their overall equipment efficiency index each day to understand how smoothly their production is running. The overall equipment efficiency index can also indicate malfunction in production and in which area the company should make improvements [30].

2.3. Implementation of SMED Method

The SMED method implementation can be indicated in the algorithm form. Fig. 10 indicates steps on how algorithmically the should be SMED method implemented during the changeover process [33].

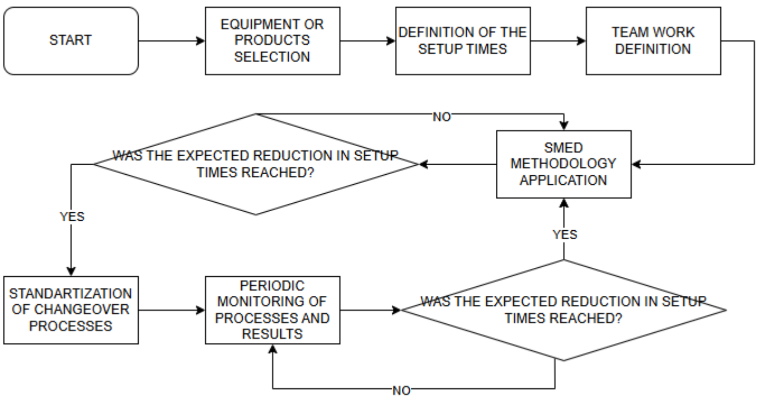

Fig. 10. Steps of SMED method implementation [33]

The implementation of an SMED can be performed based on the seven steps that are indicated below in Fig. 11. But mainly focus should be made on the first five steps because they have almost the biggest impact on reducing changeover time [34].

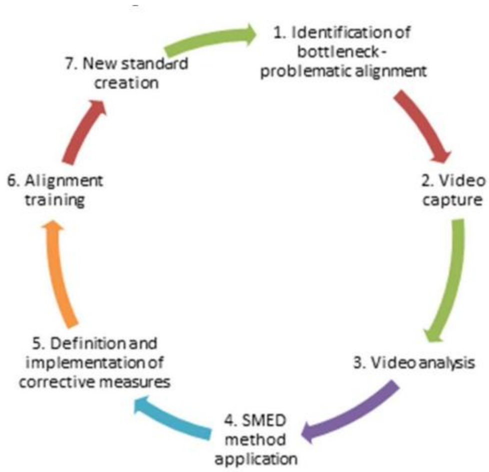

Fig. 11. SMED method implementation [34]

The first SMED method is the identification of bottlenecks in a chosen production line. It consists of a determination on which production line the SMED method will be applied. To identify and determine bottlenecks, value stream mapping can be used, or the OEE (overall equipment efficiency) calculation of the production area. The workplace, which indicates the total capacity of production, must be chosen. In this case, the SMED method is applied to a production line that produces direction indicators. The indicator production line has an impact on another production line that produces the finished product – exterior mirrors. The equipment of the production is a vibrational welder. Replacement of the vibrational welder is problematic, from the perspective of an organization and from a time point of view [34, 35].

The second step is a video capture. For the employee who will apply the SMED method to a production line, it is important to collect all necessary data on how the current changeover process is performed. The easiest way to capture all necessary data of how the changeover process is applied is to make a video and after that analyze the video of how the operator performs vibrational welder change [34, 35].

In the third step of the SMED method implementation, video analysis should be performed. The video analysis can be done with the optional equipment – phone, tablet, etc. [34, 35].

2.4. Application of SMED Method in Medium-Sized Enterprise

In this case, the work of individual maintenance operators was divided into different activities indicating their duration and meaning of the activity. In the first step, after a changeover, activities were categorized into four main groups according to their meanings: value-added activities, necessary activities, loss, and waiting. In Table 3 the first operator activities were separated and assigned to their meaning [34].

Table 3. First operator activities and their duration [34]

Activities	Duration, seconds	Meaning
Walking to a new form	18.8	loss
Searching for the form	8.5	loss
Waiting for trolley positioning	26.1	waiting
Loading the form on the trolley	4.6	necessary activity
Moving with the empty trolley to the welder	27.1	loss
Walking around the welder	15.8	loss

Activities	Duration, seconds	Meaning
Inserting the centering pins	19.5	value-added activities
Carrying the table up to the stop of the centering pins	23	value-added activities
Loosening the upper screws	37.2	value-added activities
Waiting for the second operator	8.3	waiting
Dropping the table to the tool change position	8.7	value-added activities
Problem loosening of centering pins	31	loss
Loosening the 2 lower screws	37	value-added activities
Pulling the pins out of the form	3	value-added activities
Shifting the unlocked form	2.2	value-added activities
Walking for the new form (behind the welder)	12.1	loss
Bringing a new form to the welder	9.9	value-added activities
Moving the new form to the welder	7.3	value-added activities
Walking to the front of the welder	16.4	loss
Centering the shape with the centering pins	20.3	value-added activities
Tightening the lower screws by hand	4.1	value-added activities
Tightening the lower 2 screws with the key	27.7	value-added activities
Taking the table up to the stop	14.5	value-added activities
Tightening the upper screws	41.6	value-added activities
Securing the table at the bottom	9.4	value-added activities
Removing the centering pins	10.6	value-added activities
Implementing a parameter set	26.7	value-added activities
Bringing the preheating device to the line	35.6	necessary activities
Installing a preheating device	33.5	value-added activities
Automatic tuning of the head and welding of the 1st pieces to perform a destructive test	79.4	value-added activities
Destructive test	40	value-added activities
Waiting for production release	155.4	loss
Releasing the production by quality worker	33.4	necessary activities
Total changeover time	848.7	

In Table 4, the second operator activities were separated and assigned to their meaning [34].

Table 4. Second operator activities and their duration [34]

Activities	Duration, seconds	Meaning
Walking for the form	19.8	loss
Moving the trolley to the form	5.4	necessary activities
Trolley positioning	32.4	necessary activities
Mold transportation to welder	33.6	necessary activities
Waiting for the welder release by the first operator	50.3	waiting
Walking to the welder door	4.7	loss
Opening the welder rear door	4	necessary activities
Loosening the screws on the upper form	28.2	value-added activities
Closing the welder door	10.8	necessary activities
Waiting for the first operator	39.1	waiting
Walking to the welder door	2.7	loss
Opening the welder door	3.1	necessary activities
Loosening the 2 bottom screws	21.7	value-added activities
Pulling the connectors out of the form	11.1	value-added activities
Moving with the empty trolley to the welder	5.3	necessary activities
Loading the form on the trolley	6.7	necessary activities
Moving the trolley sideways	7.3	necessary activities
Adjusting the trolley towards the welder	7.3	necessary activities

Activities	Duration, seconds	Meaning
Moving the form into the welder	6.3	value-added activities
Connecting the connectors	26.8	value-added activities
Tightening the bottom screws	41.5	value-added activities
Closing the welder door	7.9	necessary activities
Waiting for the first operator	12.7	waiting
Walking to the welder door	3	loss
Opening the welder door	4.6	necessary activities
Tightening the screws of the upper form	24.4	value-added activities
Closing the welder door	6.2	necessary activities
Moving the empty trolley from the new form	31.6	necessary activities
Walking for the form	19.2	loss
Moving the trolley with the old form	28.5	necessary activities
Trolley positioning	13.9	necessary activities
Inserting the form into the rack	15.8	necessary activities
Total changeover time	**569.3**	

After the separation of activities that were performed by two operators, researchers created a pie chart to visually indicate how many percentages each activity consists of. In Fig. 12 the total duration of the first operator was 848.7 seconds, and most of the activities were value-added. The first operator performed and ensured the entire process of the changeover. Starting with preparation activities, activities during changeover, and activities that have to be performed by quality employees. All the activities mentioned in the tables above are internal and only performed when the equipment is not running. The operator performed his task related to welder activities and only after that it started performing activities related to the equipment that is needed for production [34].

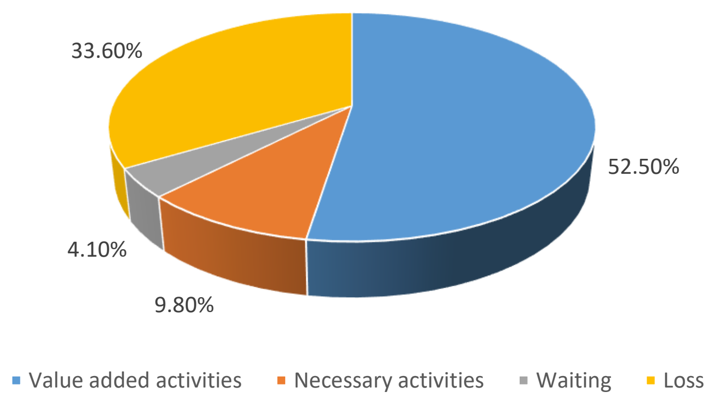

Fig. 12. First operator activities performed during the changeover [34]

Fig. 12 indicates that the value-added activities were around 53% and consisted of 445.8 seconds of the total changeover time. Non-value activities had a duration of 402.9 seconds, which can be indicated in percentage – 47%. Nonvalue activities indicated that the losses were 285 seconds or 34 percent, 34.4 seconds wait or 4 percent, and 83.5 seconds or 10 percent necessary activities [34].

Fig. 13 indicates the second operator's activities in the form of percentages. The total duration of the second maintenance worker activities time is 569 seconds. The total duration of the second maintenance worker's activities is shorter because he only performs specific activities [34].

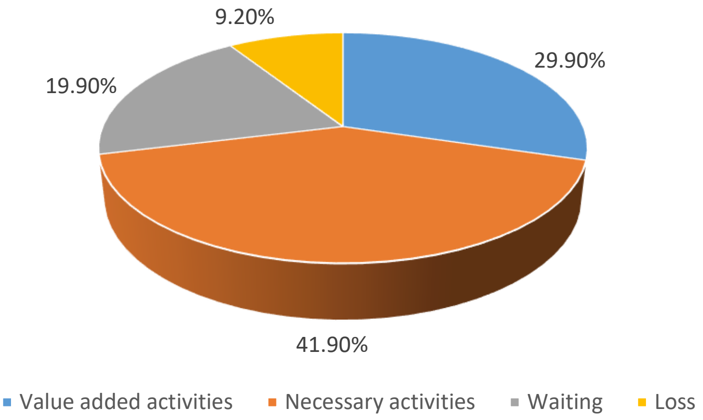

Fig. 13. Second operator activities performed during the changeover [34]

Fig. 13 indicates that nonvalue activities consisted, in total, of 71 percent. The total duration of that percentage would be 376 seconds. 30 per cent of the total duration was value-added activities that were performed by the second operator. From the section of nonvalue activities, the biggest part had a necessary activity, around 42 percent, then it was waiting time – around 20 percent, and the lowest percentage part consisted of loss [34].

Fig. 14 indicates the total duration of combined operator activities. The total time of both operator activities was 1384.7 seconds. Value-added activities, as indicated in Fig. 14 show, were around 44 percent, necessary activities were 22.2 percent, waiting around 10 percent, and loss 24.2 percent [34].

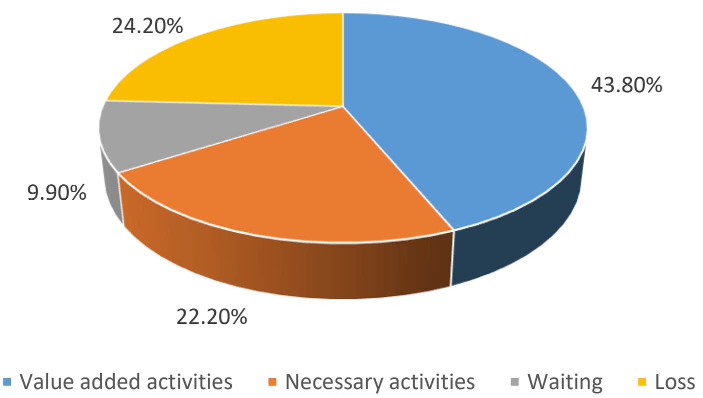

Fig. 14. Combined operator activities performed during the changeover [34]

During the changeover analysis and SMED application, it is important to find and indicate the main wastes that in the future can be eliminated and the total duration of the changeover can be reduced. Below is indicated what kind of waste could be eliminated to reduce changeover time.

- Locating for needed tools in a rack;
- Walking during the changeover of both operators' workers;
- Second operator waiting time, while the first operator will finish activities;
- Waiting time for quality employees to release production;
- Repeated operations, performances or activities;
- Tasks that should be performed together are performed individually;
- Waiting time for part release [34].

The main waste of production operators is indicated above. The main causes of waste should be reduced as much as possible during the changeover application [34].

The application of the SEMD method seeks to optimize equipment utilization, and production in small lot sizes, reduce downtime of the equipment, and reduce time when the machine is not working. Also shortening the time of changeover preparation, and machine adjustment can reduce stock. Due to high product variation in the manufacturing company, it forces the company to make changeovers frequently. To reduce the changeover time the SMED method should be applied to a chosen production line. To optimize the process in the best possible way. The four-step procedure must be applied to perform the changeover as efficiently as possible. The SMED method can be applied according to different approaches. Primarily it is applied from the five to ten steps method. The first steps of the SMED application are the same [19, 34]:

1. Observation of primary situation – identification of used tools, equipment, and materials during the changeover. Locations where necessary tools can be found identification and how operators move around all other aspects in a process;
2. Communication with the operator – during communication can be more easily understandable and identified problems during changeover;
3. Video recording – helps to identify all movements and operations during the changeover;
4. Video analysis – during video analysis can be identified why changeover takes so long;
5. SMED method application – applying the SMED method to the chosen production line to reduce changeover time and ensure smoother product change;
6. Implementation of corrective measures – after analysis and application of the SMED method, corrections should be standardized and applied during future changeover applications [19, 34].

Firstly, a general analysis of the SMED method should be carried out. Most often video analysis is the best way to analyze how the changeover or setup is performed. Based on activities the total changeover time can be analyzed. The total changeover time can be indicated in the form of the chosen chart: pie, vertical, horizontal. In this case, activities were divided into internal and external, according to whether the equipment could still run during the performance of activities, or it should be shut down. Activities that can be classified as external [34]:

- Walking to take new tool form;
- Searching time for a form;
- Waiting time for positioning trolley;
- Loading trolley with a form;
- Walking back with a trolley [31, 34].

Similar activities were performed by the second operator, below external activities of the second operator are indicated [34]:

- Walking to take a form;
- Moving trolley with a form;
- Walking to welder;
- Positioning the trolley;
- Placing old production form on a rack [31, 34].

The total duration of internal activities for the first operator decreased from 848.6 seconds to 754 seconds, by converting internal activities into external, which can be performed while equipment is still running and not to be taken into consideration as a changeover time. For the seconds' operator total duration of activities was reduced to 335.8 seconds – which indicates that the time that the second operator performed during the changeover was approximately 5 and a half minutes [34].

The second step can be related to the elimination of activities such as internal, walking or waiting time. This step also includes the elimination of inefficient or unnecessary time. It is important to reduce or eliminate the time which is related to searching and walking activities. In this case, the spaghetti diagram can have an impact. The spaghetti diagram in visual form will indicate the walking activities of an operator during the changeover. It will help to analyze and understand how long it takes to perform each walking activity. To avoid the additional searching and walking time, a list of needed equipment, tools, and materials should be prepared before performing changeovers, while the previous production is still running. In that case, the operator will know which tools will be needed to perform the changeover. Forms should be created and standardized in a way that would be accessed by everyone in the company [34].

Activities indicated in Table 5 are internal activities, which cause the most waste during changeover, should be with the timestamp notes; to know and understand how long it takes to perform each of the activities. Internal activities also indicate how much downtime equipment faces each changeover. After the analysis of how long it takes to perform internal activities, it should be aimed to reduce as much time as possible for internal activities. As an example, it can be achieved by the proposed ideas and measures in Table 5 [34]:

Table 5. Solutions to reduce internal activities time [34]

Waste	Proposed measure	Benefits
One operator watching another how he works	Inform a colleague about operation completion loudly	Eliminated unnecessary walking
Movement to bring back the trolley to the warehouse	Procurement of a trolley with push and pull system	Eliminated unnecessary walking, improvements in ergonomics
Waiting for materials preparation during downtime	Preparation of the materials during previous production	Reduces equipment downtime

When ideas are generated about how to reduce internal activities and solutions provided, it is time to think about how it is possible to reduce external activities during the changeover. As an example, proposed solutions and ideas can be applied in the manufacturing company to reduce external activities in Table 6 [34] .

Table 6. Solutions to reduce external activities' time [34]

Waste	Proposed measure	Benefits
Two workers transporting form to the machine	Procurement of a trolley with a push-pull system	Elimination of external activities that are performed by the second operator. Reduction of activities that are related to transferring a form
Looking for a tool for production	Implementation of 5S	Looking for a tool time time-reduced
Long-distance walking to take raw materials	Prepare materials before the production	Reduces walking and waiting time

Implementation of the 5S method in the production area can have a huge impact during the changeover and reduce its time. It helps to orientate more easily on the shop-floor area, operators can know where necessary tools belong, and employees work in a clean, tidy, and safe environment [19, 34, 36].

The fourth step of the SMED method mainly focuses on the total time of the changeover. The main action is to reduce internal activities time, convert as many as possible internal to external activities, and eliminate waste from a changeover process. To reduce the total changeover time, the focus should be focused on products, materials handling and flow, collection of information, maintenance, cleaning, adjustment, and control. The proposed solution for how can be total time of the changeover duration reduced, in this case, is indicated below [34–36]:

- Preheating component can be brought by the second operator before changeover and installed during changeover;
- Activities that were performed by the second operator can be performed by the first operator, to reduce external activities' time [34].

After the application of proposed solutions during the changeover, a pie chart can be drawn to indicate and compare how much time was reduced by applying the SMED method. Percentages will indicate what part of a changeover it took to perform operators after application of solutions [34].

Fig. 15 indicates the result of the first operator after the application of the solutions on how total changeover time was reduced and activities were regrouped. In the end, activities that added value to the changeover process were 51%, and non-added value activities were 49%. The total percentage of non-value activities increased but activities related to loss significantly decreased [34].

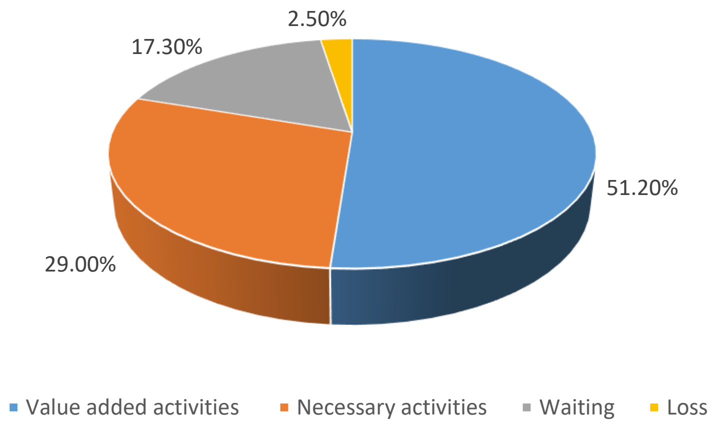

Fig. 15. The first operator, activities performed during changeover after solution application [34]

Fig. 16 indicates the second operator activity in percentage after implementation of proposed solutions. The pie chart indicates that the value-added activities are 52% of all changeover time. The non-value-added activities indicate that in total it was 48 percent. From the second operator all activities which were presented as a loss were eliminated. Other activities included in the category of non-value-added activities were reduced in percentage. Value-added activities increased from 30% percent to 50% [34].

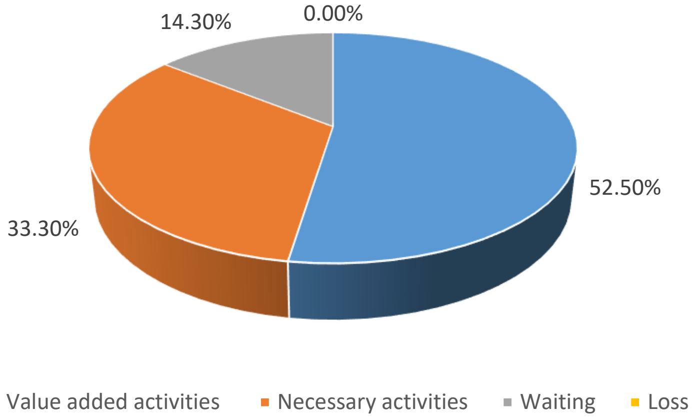

Fig. 16. The second operator, activities performed during the changeover after the solution application [34]

Fig. 17 indicates the total duration of both maintenance workers of combined changeover time. The total percentage at the end of the changeover was 51.6% of value-added activities and non-value activities were around 48 percent. The main idea of this methodology was to reduce the total duration of the changeover process performed in the production area. Provided solutions rely on the previously performed changeovers and made comparisons between them. The main time of the changeover was 848.6 seconds (14 minutes and 08 seconds) and was reduced to 607.5 seconds (10 minutes and 07 seconds) per changeover, which indicates that the best result was achieved in the reduction of the changeover time. The worst thing is that the changeover process was performed while the equipment was shut off, which means only external activities were performed, which indicates that the equipment still will face a shutdown of 607.5 seconds [34].

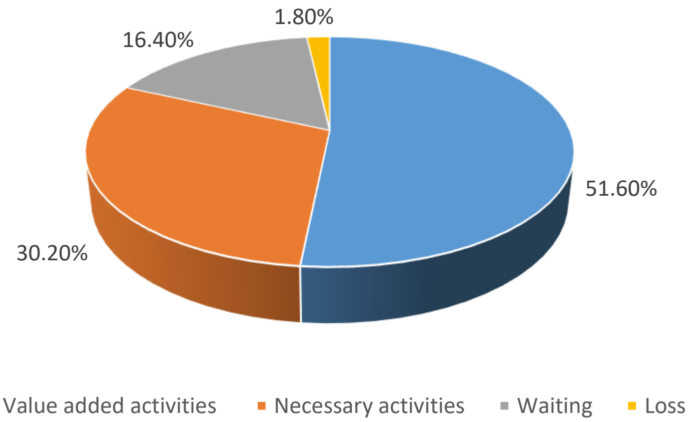

Fig. 17. Both operator activities performed during the changeover after the solution application [34]

In general, this SMED method application for changeover process improvements is most suitable and mostly applied in industrial companies. The main idea of this changeover process is to reduce the changeover duration, make sure that the changeover is performed by one operator, and eliminate non-value-added activities. In this case, all main steps are performed to reduce the changeover, which indicates that it could be taken as an example to apply the SMED method and reduce the changeover.

2.5. Application of SMED Method in Small Enterprise

The application of the second SMED method example is very similar to the example one. SMED method was applied to a different production line, but applications do not have any difference. In example two of the SMED method application, a team was formed to perform the changeover process and have their roles. In this case, the changeover process was applied to a polyethylene terephthalate bottle-blowing machine. The main functions which must be performed during the changeover [37]:

1. Perform and carry out equipment conversion;
2. Make a video analysis of the performed changeover process;
3. Analyze the current situation of a changeover and find better solutions to how to improve it [37].

In this case of a changeover, the first stage is status quo, in other words, stage zero. Current situation analysis was performed by analyzing equipment and operator activities performed during the changeover, with detailed descriptions, calculations of time, and indication of operations. Table 7 indicates what kind of activities were performed during the changeover and how long it took to perform each specific activity [37].

Table 7. Analysis of the changeover process [37]

Step number	**Name of activity**	**Operation time (HH:MIN:SS)**
1	Unloading the equipment from previous production	00:01:45
2	Ampoule wrenches preparation	00:00:30
3	Switching to pre-form tray	00:00:20
4	Empty baskets placed on pre-forms	00:01:55
5	Backfilling of old preforms from the hopper	00:05:10
6	Old pre-forms exportation	00:02:10
7	Pre-forms transitioning to the mold change stand	00:00:25
8	Closing the mold cooling water supply to the machine	00:00:45
9	Putting gloves on	00:00:15
10	Transition to the mold shelf	00:00:25
11	Taking up required forms	00:03:35
12	Bringing mold to put into the machine	00:00:40
13	Walking to operator premises for cleaning and taking paper towels	00:00:40
14	Returning to the equipment	00:00:20
15	Removing old mold and placing new ones	00:20:00
16	Moving old molds with trolleys to storage racks	00:03:50
17	Returning to the equipment	00:00:20
18	Rods cleaning	00:14:00
19	Disinfection of mold	00:09:00
20	Going to the control panel to switch it on	00:00:15
21	Waiting for mold positioning	00:01:00
22	New recipe selection	00:01:10
23	Waiting for the recipe to be loaded	00:02:00
24	Transition from machine panel to performing	00:00:20
25	Preparing new pre-forms for production	00:03:50
26	Going back to a control panel	00:00:25
27	Waiting until the stove warms up	00:02:00
28	Batch production – speed setting of the machine	00:01:05
29	Collecting bottles for strength test	00:01:05
30	Moving bottles to strength test equipment	00:00:35
31	Perform bottle strength test	00:15:00
32	Going to the machine panel	00:00:30
33	Taking bottles for control weighing test	00:01:00

Step number	Name of activity	Operation time (HH:MIN:SS)
34	Walking to the operator’s premises	00:00:20
35	Weighting bottles	00:15:00
36	Walking from the operator’s premises to the equipment	00:00:20
37	Checking parameters that were set on the equipment	00:01:30
38	Cleaning the workplace	00:01:30
39	End of changeover (Total duration)	01:52:20

The total duration of the changeover was 1 hour, 52 minutes, and 20 seconds. In total 38 activities were performed while making this changeover. In this example of the changeover, the second step is dividing activities into internal and external. Table 8 indicates how the division was made into internal and external activities. To get a better understanding of activities and their natural operations, each activity was assigned to a different category, categories were as follows – W for waiting, C – for cleaning, P – for preparation, A – for adjustment, T – for transport and E – for exchange [37].

Table 8. Division of activities to internal and external [37]

Step number	Internal or external	Category	Step number	Internal or external	Category
1	I	P	20	I	T
2	E	P	21	I	W
3	I	T	22	I	P
4	I	P	23	I	P
5	I	P	24	I	T
6	I	T	25	I	P
7	I	T	26	I	T
8	I	P	27	I	W
9	E	P	28	I	A
10	E	T	29	I	P
11	E	P	30	I	T
12	E	T	31	I	P
13	E	T	32	I	T
14	E	T	33	I	P
15	I	E	34	I	T
16	I	P	35	I	P
17	I	T	36	I	T
18	I	C	37	I	A
19	I	C	38	E	C

From Table 8, it is possible to see that during the changeover there were more internal activities than external activities. Most of the activities are related to preparation steps, but also during the changeover, the operator faces a lot of activities related to transport, which indicates excessive traffic in the workplace. In this case of changeover, due to excessive traffic in the workplace, a spaghetti diagram could also be applied to get a better understanding of how long it takes to perform each walking activity and to see the operator's walking route. Walking activities can be reduced by support of a spaghetti diagram or other walking routes could be chosen during the changeover [37].

Separation of internal and external activities allows us to analyze the changeover process further – transform internal operations into external, ones and eliminate waste activities. Table 9 indicates which internal activities can be transformed into external ones and which activities should be eliminated from changeovers [37].

Table 9. Transformation of internal activities into external [37]

Step number	Now	After that	Step number	Now	After that
1	I	I	20	I	I
2	E	E	21	I	I
3	I	E	22	I	I
4	I	E	23	I	I
5	I	E	24	I	Elimination
6	I	E	25	I	E
7	I	E	26	I	Elimination
8	I	E	27	I	I
9	E	E	28	I	I
10	E	E	29	I	I
11	E	Elimination	30	I	I
12	E	E	31	I	I
13	E	Elimination	32	I	I
14	E	Elimination	33	I	I
15	I	I	34	I	I
16	I	E	35	I	I
17	I	E	36	I	I
18	I	Elimination	37	I	I
19	I	Elimination	38	E	E

After the transformation of internal activities into external, 9 activities were transferred from internal to external activity. Seven of the activities were eliminated or could be indicated as unnecessary. Table 10 indicates solutions and ideas that can be implemented or performed to reduce the changeover, that changeover could take less time. Solutions for activities that will be eliminated are also provided in Table 10 [37].

Table 10. Operation division to internal and external activities [37]

Step number	Now	After that	Solution
11	E	Elimination	There will be no need to remove the mold from a rack, in the future trolleys will remove and deliver mold from the racks
13	E	Elimination	Paper towel preparation will be performed together with a second activity
14	E	Elimination	Activity will be eliminated due to action of activity 13
15	I	I	The introduction of trolleys will reduce a bit of changeover time, but to performance of 18 and 19 tasks will increase the changeover time
16	I	E	Activity will be performed at the end of the changeover
17	I	E	Activity will be performed at the end of the changeover
18	I	Elimination	This activity will be performed when the old mold is removed and setting new one, it will reduce cleaning time
19	I	Elimination	This activity will be performed when the old mold is removed and setting new one, disinfection time will be reduced
24	I	Elimination	Activity eliminated due to action of activity 25
25	I	E	This activity will be performed as soon as old pre-forms are emptied
26	I	Elimination	Activity eliminated due to performance of action 25
31	I	I	The strength test will be performed only with one bottle because quality problems did not arise.
35	I	I	The weight test will be performed only with one bottle because quality problems did not arise.

After analysis of how the changeover process is performed in the first stages, the third stage is to make improvements for individual operations. After internal activities were transferred to external activities and eliminating unnecessary tasks, the decision was made to perform specific operations, in a sequence way, to eliminate unnecessary walking and ensure better ergonomics. Some of the activities were merged into one task. In Table 11, the sequence of tasks' performance is indicated, including those activities that were performed before, during, and after changeover. The total changeover time after the application was reduced to a total of 50 minutes and 55 seconds when it took around 2 hours to perform the changeover. Activities that can be taken into consideration are activities that are performed during the changeover. The total changeover can be only described by activities that are performed during the changeover, as indicated in Table 11. Activities before and after can be performed outside of the changeover and those activities' duration does not belong to the total changeover duration. When determining the order of how activities were performed during the changeover, attention was paid to how the changeover activities were performed. Operators while taking off and transporting tools made unnecessary movements. To ensure a more comfortable performance for the operator of a changeover, swivel trolleys were introduced which helped to improve the ergonomics of the work [37].

Table 11. Operations after eliminating and converting internal to external activities [37]

Step number	**Name of activity**	**Operation time (HH:MIN:SS)**
	Tasks performed before the changeover	
1	Preparing ampoule wrenches and taking paper towels	00:00:40
2	Switching to perform tray	00:00:20
3	Placing empty baskets on pre-forms	00:01:55
4	Emptying old pre-forms from hopper	00:05:10
5	Exporting old pre-forms	00:02:10
6	Preparation of new pre-forms for production	00:03:50
7	Transitioning pre-forms to the mold change stand	00:00:25
8	Closing the mold colling ware system	00:00:45
9	Putting gloves on	00:00:15
10	Transition to the mold shelf	00:00:25
11	Bringing and putting mold into equipment	00:00:40
	Tasks performed during changeover	
12	Emptying equipment from previous production	00:01:45
13	Removing old molds, setting up new	00:30:00
14	Going to the control panel to switch on	00:00:15
15	Waiting until mold positions	00:01:00
16	Electing new recipes on the control panel	00:01:10
17	Waiting until the recipe is loaded	00:02:00
18	The stove needs to warm up	00:02:00
19	Setting speed settings for batch production	00:01:05
20	Collecting bottles for strength test	00:01:05
21	Transitioning to strength test device	00:00:35
22	Performing strength test for one bottle	00:01:00
23	Going to the machine panel	00:00:30
24	Control of the production for bottle weight test	00:01:00
25	Accessing the operator's premises	00:00:20
26	Weight test for one bottle	00:01:00
27	Coming back from the operator's premises to the machine	00:00:20
28	Checking the parameters of the equipment	00:01:30

Step number	Name of activity	Operation time (HH:MIN:SS)
	Tasks after	
29	Moving old mold to racks	00:03:50
30	Returning to the equipment	00:00:20
31	Strength test performance for one bottle	00:14:00
32	Weight measurement test for other bottles	00:14:00
33	Workplace cleaning	00:05:00

According to the PDCA (Plan, Do, Check, Act) cycle it is not enough to check how the changeover process is going only once. The changeover process should be monitored from time to time and try to seek the best changeover time possible. In this case, during the SMED application, a changeover process was analyzed on how to convert as many internal activities as possible to external ones and eliminate tasks that do not add any value to the changeover process. In the beginning, it took around 2 hours to perform the changeover, at the end of the activity's transformation and reduction of unneeded time, the changeover process was reduced by 1 hour 10 minutes, to 51 minutes. The changeover of the production line before application of the SMED method had a long duration and tasks to perform changeover were unstructured. During the first changeover, 30 internal activities and 8 external activities were performed. In Fig. 18, a better illustration is indicated of how long it took to perform internal and external activities [37].

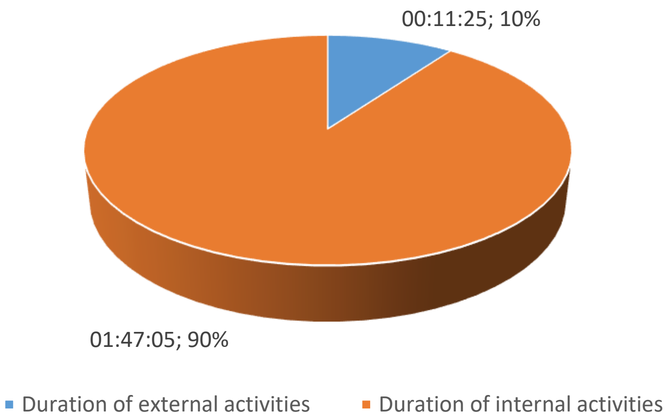

Fig. 18. Percentage of internal and external activities before SMED application [37]

Fig. 18 indicates that the most of time consisted of internal activities – 90%, or 1 hour 47 minutes, and the total time of the external activities was only 11 minutes and 25 seconds, or 10%. In the first performance of the changeover process, there is no balance between internal and external activities. Fig. 19 indicates how long it takes to perform according to their categories. Among all the internal activities the preparation activities for the changeover took the most time – around 50% of total changeover time. During the implementation phase of the SMED method, companies should think about how to eliminate preparation activities or how to perform them before the changeover starts. Other tasks, by category, took less total time and were assigned to external activities – cleaning, transporting, etc. External activity time according to the category took way less time than internal activities [37].

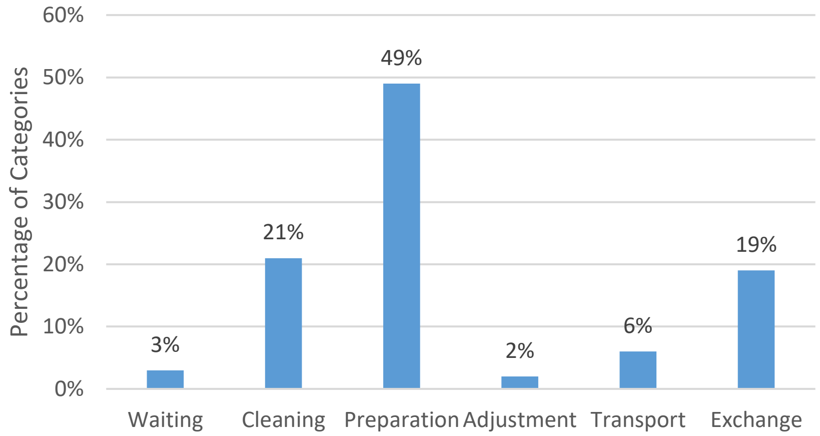

Fig. 19. Timeshare by category of internal activities before changes [37]

Fig. 20 indicates the total timeshare of tasks, by category on external activities, how long it was performed before changes [37].

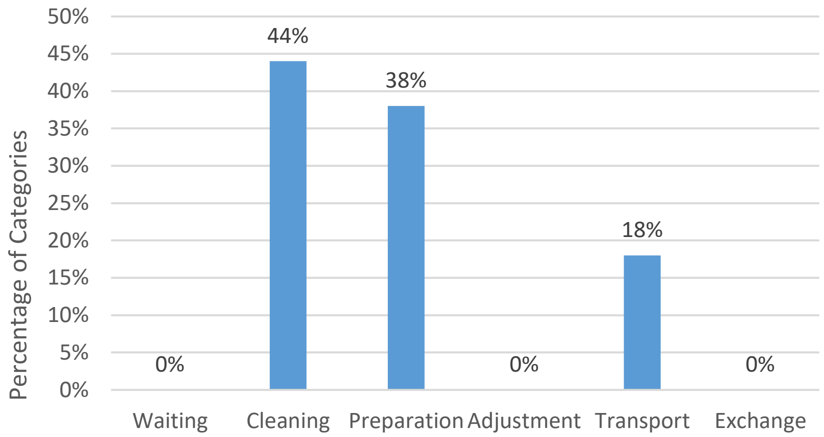

Fig. 20. Timeshare by category of external activities before changes [37]

The implementation of the SMED method decreases the total changeover time to 1 hour and 35 minutes. Fig. 21 indicates how internal and external activities time changed after the solution application [37].

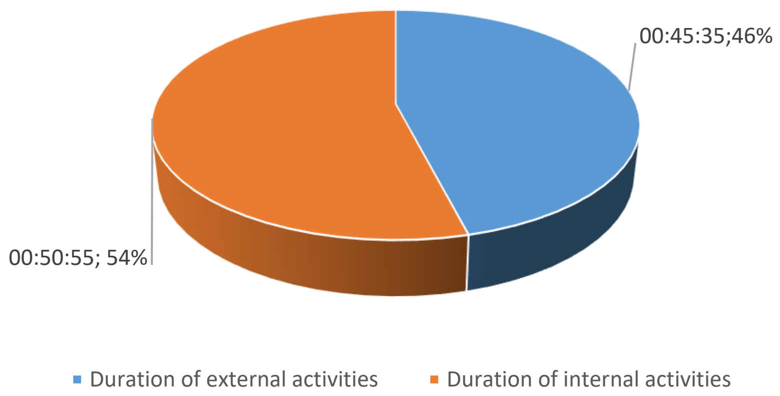

Fig. 21. Percentage of internal and external activities after SMED application [37]

Implementation of the SMED method shortened the internal activities to 54%, compared to the situation which was before applying changes. The changes applied ensured that there would be a balance between internal and external activities 54% to 46%. Fig. 22 indicates how the percentage in each category changed after the changes [37].

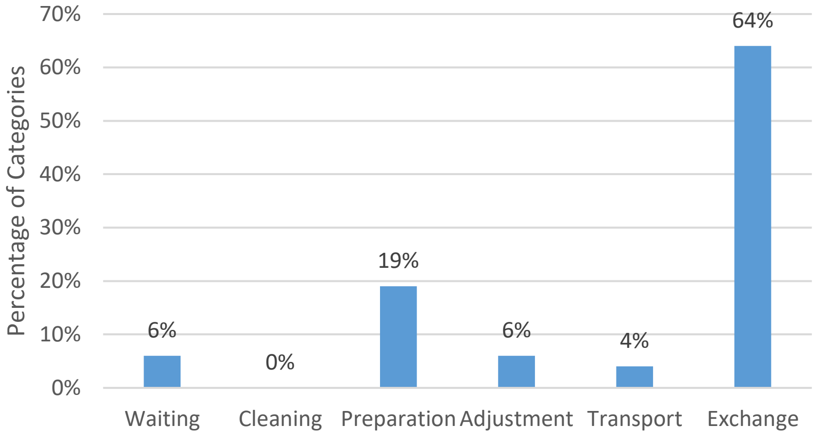

Fig. 22. Timeshare by category of internal activities after changes [37]

During the SMED implementation, most of the activities were included in the exchange category, which means were transferred from internal activities to external activities – 64% of all internal operation time. Previously most of the activities were included in the preparation section, but now all activities will be performed before shutting down equipment. Fig. 23 indicates timeshare by category of external activities after changes [37].

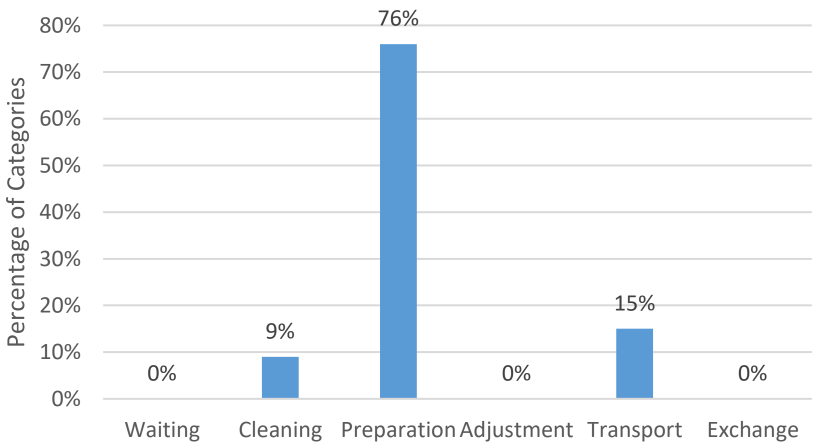

Fig. 23. Timeshare by category of external activities after changes [37]

In the end, the total changeover time was reduced from approximately 1 hour to 55 minutes to 50 minutes, which indicates a total of 1 hour reduction. In this case, the changeover takes a lot of time to be performed, so the main idea of this changeover is to reduce the changeover time as much as possible [37].

2.6. Comparison of Applied SMED Method

In the methodology part of the paperwork, two similar SMED application methods were described. One changeover was performed by two operators, which generated extra time performing the changeover process. Another example performed a difficult changeover, but the result of the reduced changeover was good. In both ways, the changeover time was reduced to proper duration. In Table 12 the main factors indicate which method will be chosen to apply similarly during the research phase.

Table 12. Decision-making on the chosen methodology application

First methodology	**Second methodology**
Changeover performed by two operators	Changeover performed by one operator
Activities are divided into value-added activities, non-value-added activities, waste and waiting	Activities are divided into internal, external, and walking activities
Finding solutions on how to reduce unnecessary activities	Finding solutions on how to transfer as many internal activities as possible to external and eliminate unnecessary activities
No time stamps are indicating how long it takes to perform each activity	In the implementation phase, indicated time stamps on activities and how long it takes to perform
Not indicating which activities are internal, which external	A clear indication of external and internal activities

As an example, will be chosen second methodology to take ideas on how changeover analysis could be performed with SMED application. A couple of ideas, like finding solutions on how to reduce changeover, dividing activities, etc., can be taken from the first methodology example. Most of the examples of how to implement the SMED method during changeover will be taken from the second methodology. A clear indication of the activities, their duration, which ones are internal, which ones are external, and most importantly a clear indication of how the total duration of the changeover was reduced and what kind of solutions were applied.

2.7. Chapter Summary

In this section, the most appropriate manufacturing method that can be applied to the changeover process was refined. The SMED method was selected as the most relevant and suitable, which can be most often applied to improve the changeover process. A production line is described on which the SMED method will be applied to changeover improvements. The SMT production line was chosen because all production from manufacturing plants starts from this line, and it is important to shorten the changeover time of the SMT line to avoid downtime in subsequent production stations. The SMT production line consists of four main stations - a solder pastes printing station, a component assembly station, a reflow oven station, and an automatic optical inspection station. This chapter provides two examples of how the SMED method should be applied and implemented. The SMED method can be applied in a company in four simple steps – perform a visual analysis of how the changeover process is carried out, try to separate the internal and external activities that were carried out during the replacement, try to reduce unnecessary activities and eliminate waste, after the application of SMED, improve the efficiency of the activities and improvements that were implemented and finally, properly train the operators on how to support the changeover process. The replacement process also affects the overall efficiency of the equipment and can affect the operation of the equipment. This section provides two examples of how other companies apply the SMED method and how the improvements have an overall impact on production. Ideas on how to apply and implement the SMED method will be taken mostly from the second example, but to receive better results at the end of the project, ideas from the first example should be also taken into consideration.

3. Research of Changeover Process Using the SMED Method

In the research phase, the changeover process will be analyzed by applying the SMED method to a chosen production line. The chosen production line is the SMT production line. The changeover process will be analyzed before applying SMED, how it is performed, what activities arise during the changeover, and how many internal and external activities are performed during the changeover. After analysis of the changeover, the SMED method will be applied to reduce the changeover duration as much as possible. After that the results of the applied SMED method will be indicated and solutions provided which helped to reduce total changeover time.

3.1. Current Situation of Changeover Process

In the first stage of the changeover process analysis, the previous results should be analyzed. In consideration, more than one operator should be taken, which performs the changeover process. To get a better understanding of how the changeover process was performed, an SMT production line was chosen and both operators performed changeover for the same production line, similar activities were made, indication of which activities were operated, and the duration of each activity was indicated.

The SMT (Surface Mount Technology) production line was chosen, for which the changeover process will be analyzed. The changeover process was performed by two different operators. Operator performance of the changeover indicates how smoothly and effectively the changeover process is performed. Comparison between operators' work can be indicated after SMED implementation to understand what deviations are given in the results, between January and February. The period on which results will be analyzed is taken – the month of January, before applying the SMED method for changeover process analysis, and – February month, which will indicate results after improvements suggestions, and application of solutions for an SMT production line. At work, two production lines – SMT one and SMT two, but both SMT production lines produce different types of products for different customers.

3.1.1. Changeover Process Performed on First SMT

Table 13 indicates the changeover durations that were performed for the first SMT production line during January on a specific monthly day. The total average time of the first SMT production line changeover process, before the SMED application, was 14 minutes and 10 seconds. In total in January were performed 90 changeovers, which indicates that the total time for the whole month of January of the changeover was 1274 minutes. There is an exception on specific days like the 8th and 21st of January. On those days, the changeover was not performed, because production was not running. As Table 13 indicates on January 18th and on January 24th the changeover time was less than 10 minutes, 8 minutes and 50 seconds, and 9 minutes and 30 seconds respectively. It indicates that the changeover was perfectly performed by the first operator. No mistakes were made, and no additional activities were performed during the changeover on those days, which indicated the perfect changeover time. Therefore, theory indicates that the best-case scenario changeover should take less than 10 minutes. The changeover time on some days can be significantly increased because the company employees come back from winter vacation and it takes some time to return to normal working pace. On the other hand, it can also indicate that the changeover time was higher because of hard product modification, which requires better preparation for changeover and longer changeover performance: special knives were used in the solder paste printing process which has to be changed. Knives changing process consumes time. Additionally, due to a lack of understanding of 5S methodology line operators waste time by performing searching activities. Poor knowledge of production management methods leads to low performance during changeovers. The overall changeover time was exported from the ERP system, which tracks the changeover times:

Table 13. SMT1 changeover duration before SMED application

Date	**Average changeover time (minutes/seconds)**	**Total changeover time (minutes)**	**Total changeover number**
Total	14 minutes 10 seconds	1274	90
2025-01-03	13 minutes 20 seconds	40	3
2025-01-04	14 minutes	56	4
2025-01-05	10 minutes 20 seconds	31	3
2025-01-06	13 minutes 15 seconds	106	8
2025-01-07	12 minutes 26 seconds	87	7
2025-01-08	-	-	-
2025-01-11	16 minutes 10 seconds	97	6
2025-01-12	12 minutes 26 seconds	87	7
2025-01-13	18 minutes 45 seconds	75	4
2025-01-14	20 minutes 30 seconds	82	4
2025-01-15	14 minutes	14	1
2025-01-17	18 minutes 30 seconds	37	2
2025-01-18	8 minutes 50 seconds	53	6
2025-01-21	-	-	-
2025-01-22	30 minutes 30 seconds	61	2
2025-01-24	9 minutes 30 seconds	19	2
2025-01-25	18 minutes seconds	109	6
2025-01-26	12 minutes 30 seconds	125	10
2025-01-27	12 minutes 17 seconds	86	7
2025-01-28	15 minutes 17 seconds	107	7
2025-01-29	2 minutes	2	1

Visual presentation of changeover time during each day and total time of changeover is indicated in Fig. 24.

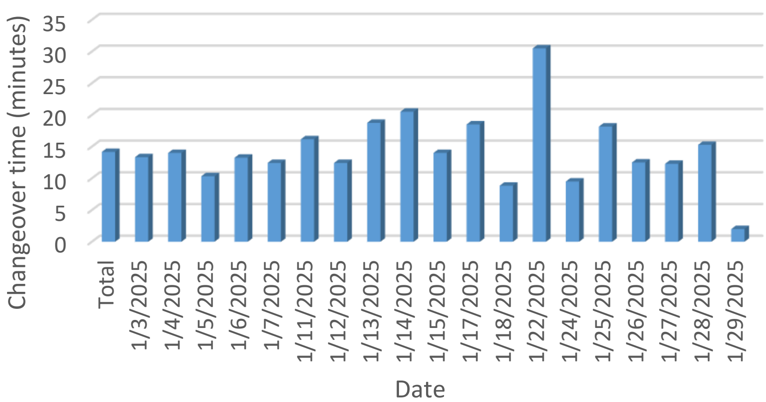

Fig. 24. SMT1 changeover time on days of January

Table 14 indicates activities that were performed by the first operator during the changeover on the first SMT production line. Activities were divided into two sections – internal and external activities. Internal activities can be only performed when equipment is shut down and external activities can be performed while equipment is still running. Most of the internal activities can be assigned to activities that are necessary to perform a changeover process. In Table 14 there is also an indicated activity name, time from what time until when it took to perform the activity, and duration of the activity.

Table 14. Activities performed by the first operator step by step on SMT1

Activity	**Time period**	**Duration (seconds)**	**I/E**
First station – PCB loader	00:00 – 01:20	80	Internal
Second station – Laser marking	01:20 – 01:50	30	Internal
Third station – Solder paste station	01:50 – 02:00	10	Internal
Loading PCBs in the first station	02:00 – 02:30	30	Internal
Changing production order in a paste station	02:30 – 02:55	25	Internal
Changing program	02:55 – 03:05	10	Internal
Changing stencil	03:05 – 03:40	35	Internal
Changing paste	03:40 – 03:50	10	Internal
Scanning support pattern fixation	03:50 – 04:40	40	Internal
Scanning frame insertion	04:40 – 05:00	20	Internal
Control panel activities	05:00 – 05:30	30	Internal
Inserting extra panels	05:30 – 06:00	30	Internal
Changing the production program in pick-and-place	06:00 – 06:30	30	Internal
Loading order	06:30 – 07:10	40	Internal
Starting pick-and-place	07:10 – 08:30	80	Internal
Control panel activities	08:30 – 09:00	30	Internal
Checking rail width	09:00 – 09:05	5	Internal
Control panel activities for oven	09:05 – 09:35	30	Internal
Waiting until the previous production products come from the oven	09:35 – 15:35	360	Internal
Starting order	15:35 – 15:45	10	Internal
AOI changing program and order	15:45 – 16:15	30	Internal
Changing to new rail	16:15 – 16:25	10	Internal
Preparing empty magazines	16:25 – 16:55	30	Internal
Searching for a product standard	16:55 – 17:10	15	Internal
Regulating magazine	17:10 – 18:10	60	Internal
End of changeover	18:10		

In Table 15 there are four external activities. External activities should be performed not during changeover, but when the previous production is still running. In this case, if the activities mentioned in Table 15 were performed before the changeover it would reduce the total changeover by 135 seconds.

Table 15. Internal activities performed by the first operator during the changeover were identified as waste

Activity	**Time period**	**Duration (seconds)**	**I/E**
Loading PCBs in the first station	02:00 – 02:30	30	Internal
Preparing empty magazines	16:25 – 16:55	30	Internal
Searching for a product standard	16:55 – 17:10	15	Internal
Regulating magazine	17:10 – 18:10	60	Internal

Table 14 indicates how long it took to perform internal and external activities for the first operator. The changeover time indicates that all the activities performed were internal activities. The total time of internal activities took 1090 seconds – approximately 18 minutes and external activities were 0 seconds because the equipment was shut down during the changeover and no external activities were performed.

From Table 15 the main activities which do not add any extra value to the changeover process are indicated below:

– Filling PCB boards in the first station takes 35 seconds, from those 35 seconds it takes 10 seconds to open the packaging in which PCBs are packed;
– Most of the changeover time is consumed by waiting for previous production PCBs to come out from an oven. It takes approximately 6 minutes. PCBs of previous production have moved out from the oven, after that operator can change the parameters of the oven and finish the changeover.

Removing the two waste activities mentioned above reduces the total changeover time of 6 minutes and 35 seconds more. The total changeover time after external and waste activities reduction could be reduced to 9 minutes and 10 seconds, which would indicate that the application of the SMED method during the changeover was successful.

The changeover process was also performed by the second operator on the same SMT production line. The changeover was more successful for the second operator. The total changeover time was 9 minutes and 20 seconds. This shows that the operator knows what he is doing during the changeover, or the production of another product is much easier, and the changeover does not take much time. Table 16 indicates how the changeover process is performed by the second operator on the same production line as the operator one performed.

Table 16. Activities performed by the second operator step by step on SMT1

Activity	**Time period**	**Duration (seconds)**	**I/E**
First station – PCB loading activities	00:00 – 01:00	60	Internal
Checking rails	01:00 – 01:15	15	Internal
Activities at a second and third station	01:15 – 01:30	15	Internal
Loading PCBs to the first station	01:30 – 01:50	20	Internal
Choosing a production program and APS	01:50 – 02:10	20	Internal
Control panel for pick-and-place	02:10 – 02:20	10	Internal
Setting program in solder paste station on the control panel	02:20 – 02:45	45	Internal
Changing stencil	02:45 – 02:55	10	Internal
Going to take the support pattern	02:55 – 03:20	25	Internal
Trying to put a support pattern	03:20 – 03:35	15	Internal
Scanning support pattern	03:35 – 03:40	5	Internal
Putting in frame, scanning	03:40 – 03:55	15	Internal
Changing solder paste blades	03:55 – 04:45	50	Internal
Scanning and changing solder paste	04:45 – 05:00	15	Internal
Wrong blades, taking blades off	05:00 – 05:10	10	Internal
Going to take the right knives	05:10 – 05:45	35	Internal
Scanning new blades and putting in	05:45 – 06:25	30	Internal
Control panel	06:25 – 06:45	30	Internal
Loading PCBs in station one	06:55 – 07:15	20	Internal
Launching sections	07:15 – 07:30	15	Internal
Launching new order	07:30 – 08:00	30	Internal
Advanced planning and scheduling	08:00 – 08:10	10	Internal
Control panel	08:10 – 08:20	10	Internal
Loading PCBs	08:20 – 08:50	30	Internal
Error in a pick-and-place model, fixing error, error fixed	08:50 – 09:20	30	Internal
End of changeover	9:20		

From the first point of view during the changeover, which was performed by the second operator on the first SMT line, only two external activities can be indicated:

- Going to take a support pattern from a storage place – takes 25 seconds;
- Going to take the right knife from a storage place, took for operator 35 seconds.

Knowing what kind of support pattern and knife will be needed for the changeover for further production, those two activities can be performed during previous production. It would eliminate one minute during the changeover. One minute of those two activities can be taken into consideration as a waste activity.

During the changeover for the first SMT production line, by the second operator, three more activities can be identified as waste activities:

- Putting support pattern into equipment – 15 seconds;
- Operator takes and inserts wrong knife – 10 seconds;
- Changing and inserting the right knife and scanning – 30 more.

Fifty-five more seconds are generated by performing unnecessary activities. As a solution for unnecessary time generated by knife activity can be proposed, the knives should be prepared before the changeover, and normal and standardized documentation should be written. Table 16 indicates how long it took to perform the changeover and only internal activities for a second operator on the first SMT production line during the changeover were performed.

3.1.2. Changeover Process Performed on Second SMT

The changeover process was also performed on the second SMT production line by the same operators. Looking at the results of the second SMT production line, the average changeover time during January was 13 minutes and 58 seconds and during January on the second SMT production line, it was 149 changeovers, which in total took 2082 minutes. Only on 16th of January equipment was not running and no changeovers were carried out. Table 17 indicates the result of the second SMT production line of the changeover process in January.

Table 17. SMT2 changeover duration before SMED application

Date	Average changeover time (minutes/seconds)	Total changeover time (minutes)	Total changeover number
Total	13 minutes 58 seconds	2082	149
2025-01-01	10 minutes 26 seconds	94	9
2025-01-03	14 minutes 20 seconds	43	3
2025-01-04	14 minutes 45 seconds	177	12
2025-01-05	12 minutes 42 seconds	89	7
2025-01-06	11 minutes 12 seconds	56	5
2025-01-07	12 minutes 33 seconds	113	9
2025-01-08	14 minutes 12 seconds	71	5
2025-01-10	10 minutes	10	1
2025-01-11	14 minutes 54 seconds	149	10
2025-01-12	17 minutes 42 seconds	177	10
2025-01-13	10 minutes 07 seconds	91	9
2025-01-14	11 minutes 10 seconds	67	6
2025-01-15	15 minutes 12 seconds	76	5

Date	Average changeover time (minutes/seconds)	Total changeover time (minutes)	Total changeover number
2025-01-16	-	-	-
2025-01-18	14 minutes 54 seconds	149	10
2025-01-24	15 minutes	30	2
2025-01-25	21 minutes 26 seconds	150	7
2025-01-26	12 minutes 12 seconds	61	5
2025-01-27	17 minutes 53 seconds	143	8
2025-01-28	15 minutes 38 seconds	172	11
2025-01-29	10 minutes 47 seconds	97	9

In Fig. 25, visual representation shows how the changeovers changed during the month of January of the second SMT production line.

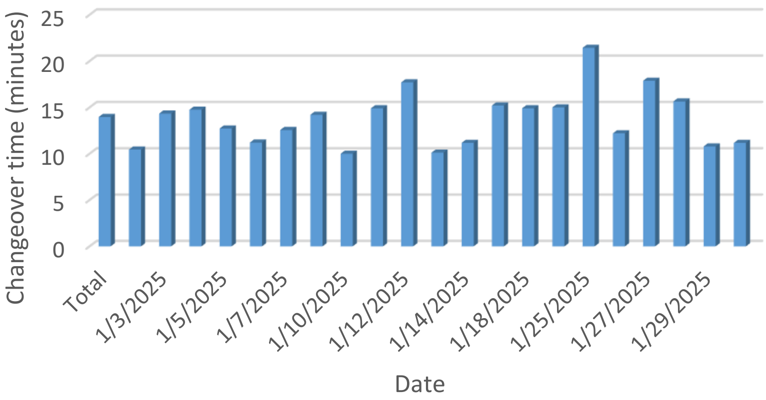

Fig. 25. SMT2 changeover time on days of January

Table 18 indicates activities that were performed by the first operator during the changeover on the second SMT production line. Activities were also divided into two sections – internal and external activities. Most of the internal activities can be assigned to activities that are necessary to perform a changeover process. In Table 18 there is also an indicated activity name, time from what time until when it took to perform the activity, and duration of the activity.

Table 18. Activities performed by the first operator step by step on SMT2

Activity	Time period	Duration (seconds)	I/E
First station – PCB loading activities	00:00 – 01:10	70	Internal
Second station – Laser marking activities	01:10 – 01:30	20	Internal
Third station – Solder paste station	01:30 – 02:40	70	Internal
Loading PCBs to the first station	02:40 – 03:15	35	Internal
Changing the program in the control panel	03:15 – 04:05	50	Internal
Changing the program in the solder paste station	04:05 – 05:05	60	Internal
The knife screw does not unscrew	05:05 – 05:25	20	Internal
Removing the knife and cleaning the paste from the knife	05:25 – 05:55	30	Internal
Changing solder paste stencil, solder paste, and support pattern	05:55 – 06:25	30	Internal
Pasta shot’s	06:25 – 06:50	25	Internal
Control panel activities	06:50 – 07:00	10	Internal
Changing program in pick-and-place equipment	07:00 – 07:30	30	Internal
Changing SMT equipment head	07:30 – 07:50	20	Internal
Going to store the old head and take a new one	07:50 – 08:50	60	Internal
Placing head and taking off head nozzle	08:50 – 09:30	40	Internal

Activity	Time period	Duration (seconds)	I/E
The operator does not know which nozzle to put in, and can't find the proper nozzle	09:30 – 10:25	55	Internal
Completion of head change	10:25 – 10:50	25	Internal
Preparing to change second head in pick-and-place equipment	10:50 – 11:35	45	Internal
Going to change the second head	11:35 – 12:05	30	Internal
Putting head in, taking off nozzle	12:05 – 12:35	30	Internal
Going to change the nozzle	12:35 – 13:00	25	Internal
Completion of nozzle change	13:00 – 13:20	20	Internal
Facing a problem, that improper nozzle installed, trying to fix the problem	13:20 – 16:20	180	Internal
APS program change	16:20 – 16:50	30	Internal
Still wrong nozzle, trying to solve the problem, problem solved	16:50 – 19:20	150	Internal
End of changeover	19:20		

Table 18 indicates that only internal activities were performed by the first operator on the second SMT production line. In total, the changeover duration was 19 minutes and 20 seconds.

Activities like waste can be identified during the changeover process and indicated in Table 19. Avoiding or reducing the activities mentioned in Table 19 can reduce changeover time by 8 minutes and 20 seconds, which would reduce total changeover time to 11 minutes.

Table 19. Waste activities performed during the changeover on SMT2 by operator 1

Activity	Time period	Duration (seconds)	I/E
Filling the first station with PCBs (opening PCBs packaging takes 20 seconds)	02:40 – 03:15	35	Internal
The knife screw does not unscrew	05:05 – 05:25	20	Internal
Going to store the old head and take a new one	07:50 – 08:50	60	Internal
The operator does not know which nozzle to put in, and can't find the proper nozzle	09:30 – 10:25	55	Internal
Facing a problem, that improper nozzle installed, trying to fix the problem	13:20 – 16:20	180	Internal
Still, wrong nozzle, trying to solve the problem, end of changeover	16:50 – 19:20	150	Internal

Table 20 indicates how the changeover was performed changeover step by step by the second operator on the second SMT production line. Activities indicated their duration and to which category they should be assigned.

Table 20. Activities performed by the second operator step by step on SMT2

Activity	Time period	Duration (seconds)	I/E
First station activities	00:00 – 01:10	70	Internal
The second station, the insertion of a magazine	01:10 – 02:10	60	Internal
Third station activities	02:10 – 03:30	80	Internal
Fourth station, solder paste control panel	03:30 – 04:10	40	Internal
Choosing a program in APS (advanced planning and scheduling)	04:10 – 04:50	40	Internal
Changing the stencil and taking off the support pattern	04:50 – 05:30	40	Internal
Walking to take a new support pattern	05:30 – 06:00	30	Internal
Trying to put a new support pattern in	06:00 – 06:45	45	Internal
Putting solder paste on a new stencil	06:45 – 07:35	50	Internal
Finishing to change solder paste in paste station	07:35 – 08:45	70	Internal
Magazine feeding, an operator places the wrong magazine	08:45 – 09:25	40	Internal
Searching for necessary magazine	09:25 – 11:05	100	Internal

Activity	Time period	Duration (seconds)	I/E
Magazine feeding	11:05 – 12:05	60	Internal
Changing head in pick-and-place	12:05 – 12:45	40	Internal
Going to place the old head and take a new one	12:45 – 13:25	40	Internal
Continue changing head	13:25 – 14:05	40	Internal
Going to put the old nozzle and take the new nozzle	14:05 – 14:45	40	Internal
Changing nozzle	14:45 – 15:15	30	Internal
Changing the second chamber head	15:15 – 15:55	40	Internal
Going to change head	15:55 – 16:55	60	Internal
Changing head	16:55 – 17:35	40	Internal
Going to place the old second nozzle and take a new one	17:35 – 17:50	15	Internal
Finishing to change nozzle	17:50 – 18:05	15	Internal
Finishing changeover with changing oven program	18:05 – 19:25	80	Internal
End of changeover	**19:25**		

Table 20 indicates how the changeover was performed by the second operator on the second SMT production line. Only internal activities were performed and in total, it took 19 minutes and 25 seconds to complete the changeover.

3.2. Changeover Situation After SMED Method Implementation

Table 21 indicates how long it took to perform changeovers in the month of February on a specific day. Not every day was a changeover performed, but in total in the month of February 64 changes were performed on the first SMT production line. In total, it took 824 minutes and the total average time for a changeover was 12 minutes 43 seconds. On February 7th and February 20th, a changeover was performed, because the production line was not running.

Table 21. SMT1 changeover duration after SMED application

Date	Average changeover time (minutes/seconds)	Total changeover time (minutes)	Total changeover number
Total	**12 minutes 43 seconds**	**824**	**64**
2025-02-02	17 minutes	34	2
2025-02-03	12 minutes 30 seconds	50	4
2025-02-04	10 minutes 24 seconds	104	10
2025-02-05	12 minutes 15 seconds	49	4
2025-02-06	9 minutes 48 seconds	49	5
2025-02-07	-	-	
2025-02-08	9 minutes	18	2
2025-02-09	11 minutes	33	3
2025-02-10	10 minutes	70	7
2025-02-11	11 minutes	22	2
2025-02-12	13 minutes 34 seconds	95	7
2025-02-13	12 minutes 30 seconds	25	2
2025-02-15	16 minutes	16	1
2025-02-16	14 minutes 08 seconds	113	8
2025-02-17	19 minutes 20 seconds	58	3
2025-02-18	12 minutes 15 seconds	49	4
2025-02-19	13 minutes	39	3
2025-02-20	-	-	-

The visual representation can be shown in Fig. 26, which indicates how the changeover process time changes during the days of February. The longest changeover took around 19 minutes, and the lowest changeover time was approximately 9 minutes.

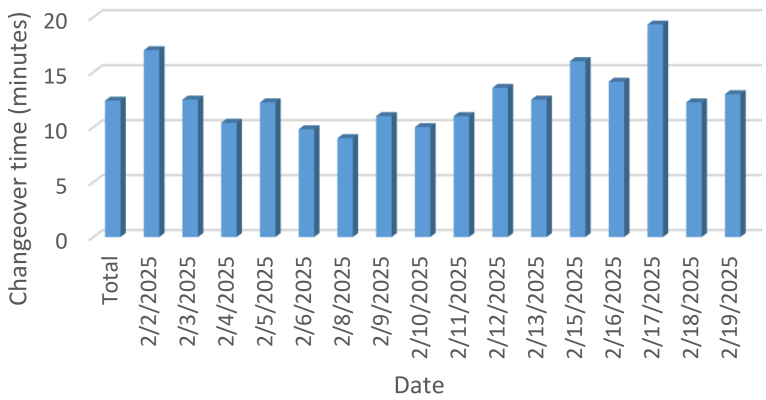

Fig. 26. SMT1 changeover time after SMED implementation on days of February

For the second SMT production line can be seen that the results are better compared with the first SMT production line after the SMED application. The total average time was reduced to 11 minutes and 53 seconds. Table 22 indicates how many changeovers were performed after the SMED application in February and the long duration of those changeovers.

Table 22. SMT2 result after SMED application

Date	**Average changeover time**	**Total changeover time (minutes)**	**Total changeover number**
Total	**11 minutes 53 seconds**	**1662**	**140**
2025-02-01	11 minutes 39 seconds	92	8
2025-02-02	12 minutes 52 seconds	123	10
2025-02-03	13 minutes 07 seconds	178	14
2025-02-04	13 minutes 06 seconds	81	6
2025-02-05	12 minutes 10 seconds	90	7
2025-02-06	11 minutes 32 seconds	116	10
2025-02-07	-	-	-
2025-02-08	11 minutes 07 seconds	46	4
2025-02-09	13 minutes	137	11
2025-02-10	13 minutes 06 seconds	118	9
2025-02-11	13 minutes 07 seconds	106	8
2025-02-12	9 minutes 10 seconds	55	6
2025-02-13	12 minutes 24 seconds	65	5
2025-02-15	11 minutes 45 seconds	102	9
2025-02-16	12 minutes 15 seconds	49	4
2025-02-17	11 minutes 06 seconds	186	17
2025-02-18	11 minutes 48 seconds	66	6
2025-02-19	8 minutes 40 seconds	52	6

Visual representation is presented on Fig. 27 to better understand how changeover time is deviating through the days of February. Not even one changeover reached a time of 14 minutes, which, taken into consideration, can be thought of as a good time.

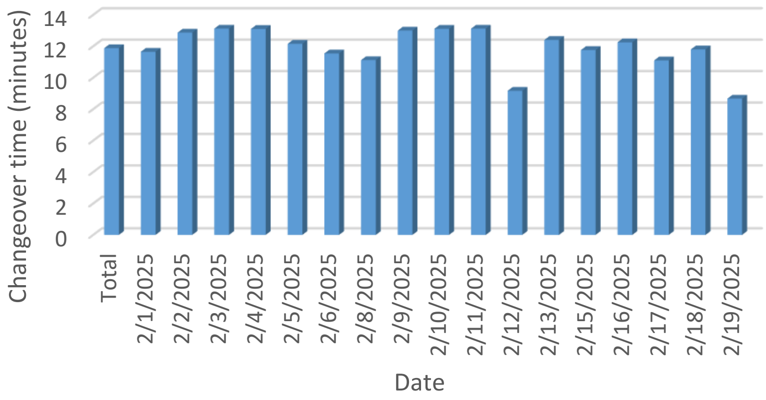

Fig. 27. SMT2 changeover time after SMED implementation on days of February

In Table 23, it is indicated how the changeover process was performed by the first operator on the first SMT production line after SMED implementation and solution application.

Table 23. Activities performed by the first operator step by step on SMT1 after SMED implementation

Activity	Time period	Duration (seconds)
Activities performed before the changeover		
Preparing empty magazines	00:00 – 00:30	30
Searching for a product standard	00:30 – 00:45	15
Regulating magazine	00:45 – 01:45	60
Inserting extra panels	01:45 – 02:05	20
Total time	02:05	
Activities performed during the changeover		
First station – PCB loader	00:00 – 01:10	70
Second station – Laser marking	01:10 – 01:40	30
Third station – Solder paste station	01:40 – 01:55	15
Loading PCBs in the first station	01:55 – 02:25	30
Changing production order in a paste station	02:25 – 02:45	20
Changing program	02:45 – 02:55	10
Changing stencil	02:55 – 03:20	25
Changing paste	03:20 – 03:35	15
Scanning support pattern fixation	03:35 – 04:05	35
Scanning frame insertion	04:05 – 04:25	20
Control panel activities	04:25 – 04:50	25
Starting pick-and-place	05:10 – 06:50	100
Changing the production program in pick-and-place	06:50 – 07:10	30
Loading order	07:10 – 07:30	20
Control panel activities	07:30 – 07:50	20
Checking rail width	07:50 – 08:00	10
Control panel activities for oven	08:00 – 08:50	50
Starting order	08:50 – 09:20	30
AOI changing program and order	09:20 – 10:00	40
Changing to new rail	10:00 – 10:15	15
End of changeover	10:15	

In Table 23 after SMED implementation and solution application can be seen that the total changeover duration performed by operator one on the first SMT production line was reduced to 10 minutes and 15 seconds. The changeover was performed for the same two products, while one was changed by another. The total changeover time in comparison with Table 17 and Table 23 was reduced by 8 minutes and it reached a time below average changeover time that was performed per one month. Table 23 also indicated that a few of the activities were performed before the changeover to reduce the total changeover time. The total duration of activities performed before the changeover was 2 minutes and 5 seconds. Those activities can be mentioned as an external activity. Fig. 28 is a visual representation of Table 23. Before applying the SMED method only internal activities were performed and none of the external activities were identified. Two minutes and five seconds cannot be counted as a total changeover time, because it was performed before the changeover.

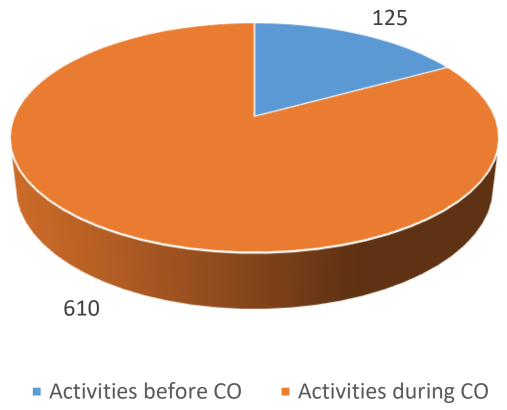

Fig. 28. Activities performed after SMED implementation for SMT1 in seconds, operator 1

Table 24 indicates the changeover process and how it was performed after SMED implementation on SMT2 and the second operator.

Table 24. Activities performed by the second operator step by step on SMT1 after SMED implementation

Activity	Time period	Duration (seconds)
Activities performed before the changeover		
Brought stencil	00:00 – 01:10	70
Brought support pattern	01:10 – 01:50	40
Brought knifes	01:50 – 02:30	40
Total time	02:30	
Activities performed during the changeover		
First station – PCB loading activities	00:00 – 01:00	60
Checking rails	01:00 – 01:15	15
Activities at the second and third station	01:15 – 01:30	15
Loading PCBs to the first station	01:30 – 01:50	20
Choosing a production program and APS	01:50 – 02:10	20
Control panel for pick-and-place	02:10 – 02:20	10
Setting program in solder paste station on the control panel	02:20 – 03:05	45
Changing stencil	03:05 – 03:15	10
Putting support pattern	03:15 – 03:40	35
Scanning support pattern	03:40 – 03:50	10
Putting in frame, scanning	03:50 – 04:00	10
Changing solder paste blades	04:00 – 05:00	60
Scanning and changing solder paste	05:00 – 05:35	35
Control panel	05:35 – 06:15	40
Loading PCBs in station one	06:15 – 06:40	25
Launching sections	06:40 – 07:20	20

Activity	Time period	Duration (seconds)
Activities performed during the changeover		
Launching new order	07:20 – 07:50	30
Advanced planning and scheduling	07:50 – 08:10	20
Control panel	08:10 – 08:20	10
Loading PCBs in station one	08:20 – 08:50	30
End of changeover	08:50	
Activities performed after the changeover		
Cleaning knives and bringing them back to storage	00:00 – 02:00	120
Bringing back support pattern	02:00 – 02:40	40
Putting back stencil in the storage room	02:40 – 03:10	30
Total time	03:10	

The changeover was performed by the second operator on the second SMT production line. Changeover was performed by changing the same two products that were produced in the previous production while applying the SMED method. The time before applying the SMED method was 9 minutes and 20 seconds. After SMED implementation, the changeover was reduced to 8 minutes, by 1 minute and 20 seconds. Table 24 activities that were performed before, during, and after the changeover. Activities related to walking, searching, cleaning, and placing back tools to storage were converted to external activities, that could be possible to perform while production is running. It indicates that the operator was well prepared for the changeover before it started to happen. Before the changeover operator prepared the right for the solder paste station, and with that reduced the changeover to 8 minutes. Also, proper training was provided for the second operator to improve changeover process skills for the SMT production line. Fig. 29 is a visual representation of Table 24, which indicates how long it took to perform each activity.

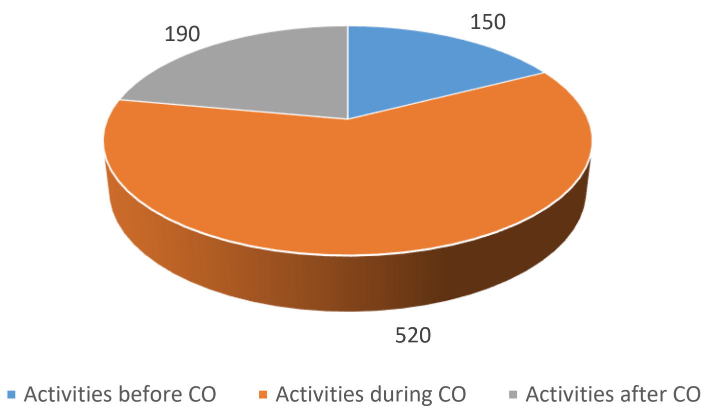

Fig. 29. Activities performed after SMED implementation for SMT1 in seconds, operator 2

The changeover process after the implementation of the SMED method and how the results changed are also indicated in Table 25.

Table 25. Activities performed by the first operator step by step on SMT2 after SMED implementation

Activity	Time period	Duration (seconds)
Activities performed before the changeover		
Going to take a stencil	00:00 – 01:00	60
Going to take the support pattern	01:00 – 01:40	40
Going to take the nozzle	01:40 – 02:10	30
Going to take knives	02:10 – 02:50	40

Activity	Time period	Duration (seconds)
Activities performed before the changeover		
Going to take pick-and-place equipment head	02:50 – 03:20	30
Total time	03:20	
Activities performed during the changeover		
First station – PCB loading activities	00:00 – 01:10	70
Second station – Laser marking activities	01:10 – 01:30	20
Third station – Solder paste station	01:30 – 02:00	20
Loading PCBs to the first station	02:00 – 02:25	25
Changing the program in the control panel	02:25 – 02:55	30
Changing the program in the solder paste station	02:55 – 03:05	10
Removing the knife and putting the correct knife	03:05 – 04:10	65
Changing solder paste stencil, solder paste, and support pattern	04:10 – 05:00	50
Control panel activities	05:00 – 05:10	10
Changing program in pick-and-place equipment	05:10 – 05:50	40
Changing SMT equipment head	05:50 – 06:20	30
Placing head and taking off head nozzle	06:20 – 06:50	30
Completion of head change	06:50 – 08:00	70
Preparing to change second head in pick-and-place equipment	08:00 – 08:35	35
Going to change the second head	08:35 – 09:05	30
Putting head in, taking off nozzle	09:05 – 09:30	25
Going to change the nozzle	09:30 – 09:50	20
Completion of nozzle change	09:50 – 10:20	30
APS program change	10:20 – 10:40	20
End of changeover	10:40	
Activities performed after the changeover		
Cleaning knives and bringing them back to storage	00:00 – 01:50	110
Bringing back support pattern	01:50 – 02:35	45
Putting back stencil in the storage room	02:35 – 03:05	30
Going to store nozzle and equipment head	03:05 – 03:30	25
Total time	03:30	

Table 25 indicates how successful the changeover process was for the first operator on the second SMT production line. The previous changeover took around 20 minutes to perform, after SMED implementation the changeover time was reduced to 10 minutes and 30 seconds, by approximately 7 8 minutes. This changeover indicates that the operator properly prepared for the changeover and all tasks which were capable of doing before the changeover operator did and it helped him to avoid 7 minutes of the changeover. The operator also performed a couple of activities after the changeover to avoid any unnecessary time during the changeover. Fig. 30 indicates how long it took for the operator to perform activities before, during, and after the changeover, which helped to reduce the main duration of the changeover time, in seconds.

The changeover process of how it was performed after SMED implementation to the second SMT production line of the second operator is also indicated in Table 26. To get a better understanding of whether the SMED implementation method was successful, an indication of both SMT production lines and how the changeover was performed should be done.

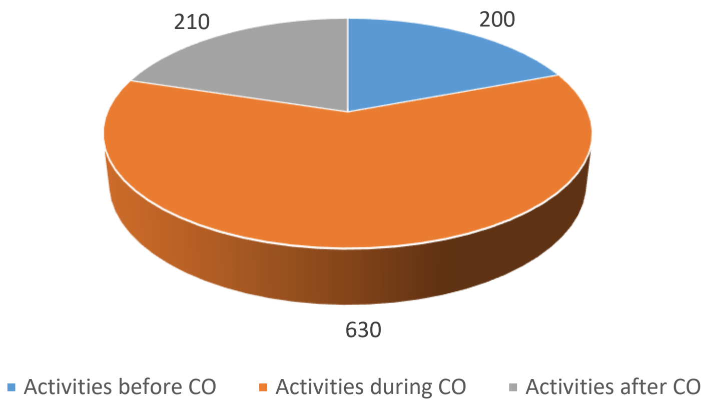

Fig. 30. Activities performed after SMED implementation for SMT2 in seconds, operator 1

Table 26. Activities performed by the second operator step by step on SMT2 after SMED implementation

Activity	**Time period**	**Duration (seconds)**
Activities performed before the changeover		
Going to take a stencil	00:00 – 01:00	60
Going to take the support pattern	01:00 – 01:40	40
Going to take the nozzle	01:40 – 02:10	30
Going to take knives	02:10 – 02:50	40
Going to take pick-and-place equipment head	02:50 – 03:20	30
Brought magazines for feeding	03:20 – 03:50	20
Total time	03:50	
Activities performed during the changeover		
Activities in the first station	00:00 – 01:00	60
The second station, the insertion of a magazine	01:00 – 01:40	40
Third station – Solder paste station	01:40 – 02:20	30
Fourth station activities – solder paste and control panel	02:20 – 02:50	30
Program change in APS	02:50 – 03:00	10
Changing solder paste stencil	03:00 – 03:30	30
Putting solder paste on stencil	03:30 – 04:10	40
Changing solder paste knives	04:10 – 04:55	45
Finishing changing solder paste	04:55 – 05:20	25
Taking off the support pattern and putting new one	05:20 – 06:30	70
Placing magazines for PCB's loading	06:30 – 06:50	20
Changing pick-and-place head	06:50 – 07:40	50
Changing nozzle	07:40 – 08:20	40
Second chamber head change	08:20 – 09:00	40
Second chamber nozzle change	09:00 – 09:50	50
Changing the re-flow oven program	09:50 – 10:10	
End of changeover	10:10	
Activities performed after the changeover		
Cleaning knives and bringing them back to storage	00:00 – 01:40	100
Bringing back support pattern	01:50 – 02:35	45
Putting back stencil in the storage room	02:35 – 03:05	30
Going to store nozzle and equipment head	03:05 – 03:30	25
Total time	03:30	

Table 26 indicates how the changeover process was reduced with the applied SMED method. From the changeover that took around 20 minutes, the changeover was reduced to 10 minutes and 10 seconds, which indicates that the result for reducing the changeover was reached. Only necessary activities were performed. Most of the activities that can be performed during the changeover by the operator were performed before or after the changeover to reduce the time performed. Fig. 31 indicates how long it took to perform activities before, during, and after the changeover in seconds.

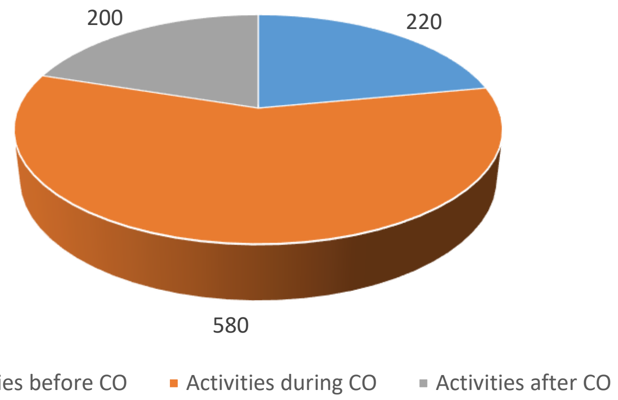

Fig. 31. Activities performed after SMED implementation for SMT2 in seconds, operator 2

After implementation of the SMED method, all the activities that do not extra value to the changeover process were eliminated from the changeover. Only activities which have an impact on the changeover process were left. Operators performed preparation activities before and after the changeover to reduce the duration of the main changeover. For both SMT production lines, improvements can be seen, how changeovers were reduced.

3.3. Comparison of Changeover Before and After SMED Implementation

Comparison can be made after seeing the result and how long it took to perform a changeover before applying the SMED method and after the SMED method application. For the first SMT production line in total were performed 154 changeovers, during the month of January, when the SMED method was not applied were performed 90 changeovers, in total it took 1274 minutes, and the average timer per one changeover was 14 minutes, and 10 seconds After SMED application, for the first SMT production line the total changeover time was reduced to 824 minutes, approximately by 450 minutes and only 64 in total changeovers were performed due to shorter month. After the SMED application, the average time per changeover for the first SMT line was reduced to 12 minutes and 43 seconds. Table 27 indicates the first SMT production line comparison of the results in January and the month of February.

Table 27. SMT1 result comparison between January and February

Production line	Month	Average changeover time (minutes)	Total changeover time (minutes)	Total changeover number
SMT1	Total	13 minutes 21 seconds	2098 minutes	154
	2025-01	14 minutes 10 seconds	1274 minutes	90
	2025-02	12 minutes 43 seconds	824 minutes	64

Visual representation of data and the result are indicated in Fig. 32 and Fig. 33. In Fig. 32 it is indicated how many changeovers were performed each month and in total and how long it took to perform them in total.

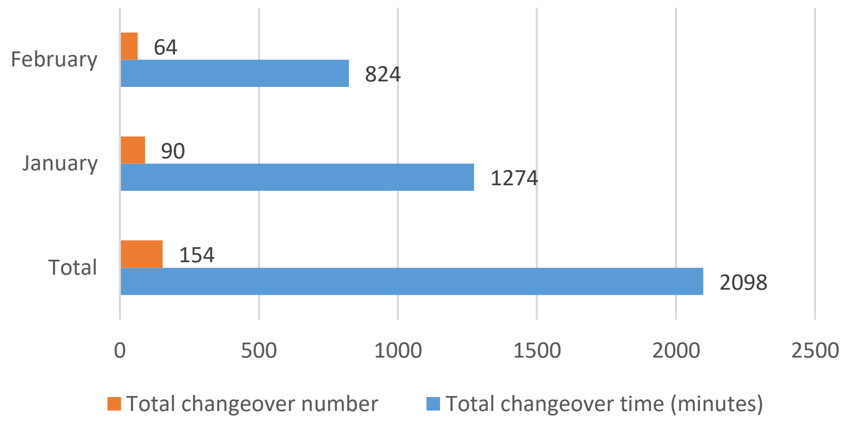

Fig. 32. SMT1 results comparison

Fig. 33 shows comparison in a percentage, how many percentages of changeovers were performed in January and February, in total on the month of January 58.44% of changeovers were performed and in February 41.56% of changeovers were performed.

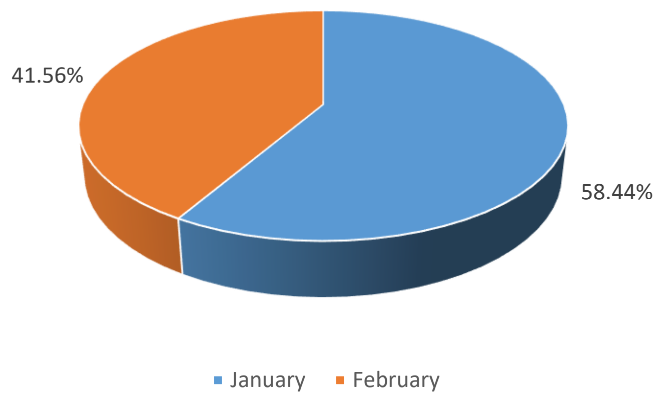

Fig. 33. SMT1 results comparison in a percentage (Changeover amount)

Compared results for the second SMT production line are indicated in Table 28. In total during the month of January and February, on the second SMT production line in total 289 were performed. In total, it took 3700 minutes and the average time per changeover was 12 minutes 59 seconds. In comparison, in January 149 changeovers were made, and in February – 140. Before the SMED application, it took a total of 2082 minutes to perform those 149 changeovers, which means that the average time per changeover was 13 minutes and 58 seconds. Looking at the data and results of February, it can be said that 9 changeovers were performed, but the total time to perform those 140 changeovers was 1662 minutes. It indicates that the average time per changeover on second SMT production in February was 11 minutes 53 seconds. The total changeover number did not reduce a lot, but the time of the main changeover was almost reduced to a single-digit minute. Table 28 indicates data and the results of the changeover process which was performed on the second SMT production line for January and February.

Table 28. SMT2 result comparison between January and February

Production line	Month	Average changeover time (minutes)	Total changeover time (minutes)	Total changeover number
SMT2	Total	12 minutes 59 seconds	3700 minutes	289
	2025-01	13 minutes 58 seconds	2082 minutes	149
	2025-02	11 minutes 53 seconds	1662 minutes	140

Of second SMT production line also has a visual representation of data, and the results are indicated in Fig. 34 and Fig. 35. In Fig. 34 it is indicated how many changeovers were performed each month and in total and how long it took to perform them in total. Fig. 34 shows a comparison in percentage, how many percentages of changeovers were performed in January and February, in total on January 51.55% of changeovers were performed and in February 48.45% of changeovers were performed.

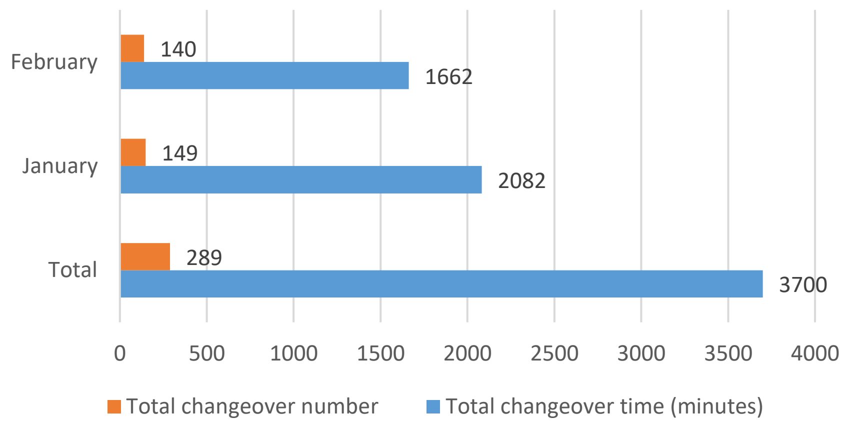

Fig. 34. SMT2 results comparison

Fig. 35 shows comparison in a percentage, how many percentages of changeovers were performed in January and February, in total on the month of January 51.55% of changeovers were performed and in February 48.45% of changeovers were performed.

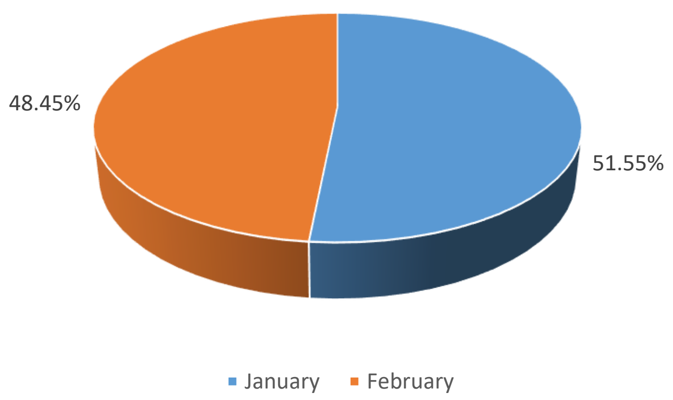

Fig. 35. SMT2 results comparison in a percentage (Changeover amount)

Despite that there were only 59 more changeovers than in the SMT1 production line, the changeover average time also took 12 seconds less on the second SMT production line. The total changeover time for the first SMT line was 1274 minutes and for the second SMT line, it was 2082 minutes, which indicates that the second SMT line, with a bigger changeover time and more changeovers, managed to reach a lower average changeover time. It indicates that the changeover was performed more effectively on the second SMT production line, despite that the total changeover time was higher.

3.4. Solutions for Reduced Changeover

To get a better understanding of why and how the changeover process duration was reduced, an indication of the solutions and their application should be mentioned. During the changeover operators faced activities that can be performed before or after the changeover. Activities and solutions which can be performed before the changeover, while the previous prosecution is still running, are indicated below.

The most time that activity takes to perform is activity related to the oven when the operator must wait until all previous production products are out of the oven, then the oven needs to cool down and only after that settings for the oven can be applied and the start of production can be done. According to the company, there is no other option to solve this issue, only by waiting that time and perform activities after the last production stopped.

The first solution to reduce changeover time and activity that could be performed before the changeover is preparing magazines for production before the changeover. The operator needs to find suitable magazines for further production. PCB should be loaded to magazines before starting the changeover. Fig. 36 indicates how the magazine should be prepared before the changeover.

Fig. 36. Magazine preparation before the changeover

The second idea is very related to the first solution. Before performing the changeover, the product standard needs to be found to regulate the magazine according to, that after production semi-finished products can be properly put into the magazine. In Fig. 36, a white PCB is placed into a magazine, and it indicates that the PCBs fit perfectly.

The third solution is to unpack and prepare materials that will be used in production, before the changeover application. As the changeover was applied to the SMT production line, the SMT production line uses PCBs and electronic components. Most of the electronic components and PCBs are packed in the cellophane packaging as indicated in Fig. 37.

Fig. 37. Electronic components packaging

Suppliers provide PCB materials in vacuum-sealed packaging, which must be opened before using PCBs or electronic materials. During the changeover, it has been seen that operator open packaging with their hands, and it takes a lot of time to do that. One of the solutions was to provide the operator with a proper knife which ensures smoother opening of the PCB packaging. As a solution to how to more effectively open electronic and PCB components packaging, it was proposed to use professional knives, or we can say opening tools as indicated in Fig. 38. Using tools as indicated in Fig. 38 will help operators to open electronic components packaging faster. Tools are also placed in their original place and marked according to standard 5S which can be seen in Fig. 38, so that operators can find tools more easily and know where they are placed.

Fig. 38. Used tool for opening electronic materials packaging

The fourth solution is to bring a support pattern that must be changed in the production line, before performing a changeover. It will reduce the changeover duration because it will be performed before. During the changeover, time could be reduced by indicating how properly to insert support pattern into SMT production line equipment. Firstly, it was hard for the operator to place it properly, because he couldn't find suitable points to place it. The operator first floated the support pattern and tried to insert it with a sliding move as indicated in Fig. 39.

Fig. 39. Sliding support pattern to insert it

A solution was proposed to mark those points so that the operator could more easily understand how to insert support patterns into the SMT production line. The solution is indicated in Fig. 40.

Fig. 40. Marked insert points of support pattern

This proposed idea also reduced the changeover, because during the changeover operator understood better how to insert support pattern into the SMT production line. For placing a support pattern into the SMT production line, the proper instructions and training were provided to the operators who perform changeover. An indication of the area where and how it must be placed should be indicated also.

The fifth solution is related to the knives which are used in the solder paste station. The system for operators indicates what kind of type knives will be used in the next production. The operator should memorize the knife code, where it is placed, and walk bring the knife before changeover, so that during changeover it would be enough only to insert them. Due to proper documentation and the 5S method implementation for the operator, it would be easy to find knives on the shelves as indicated in Fig. 41. Knives are placed in the storage cabinet and labeled according to their belongings. In Fig. 41 there is an indicated problem with a long search time. For this reason, a solution of easier ways of finding ways was implemented. Previously, marking for knives only indicated the code, which knife should be used in the solder paste station and it was hard for operators to easily find needed knives. To reduce searching time, which was around one minute and thirty seconds, and prevent wrong knives from being picked up, a solution as indicated in Table 29 was implemented, according to 5S standards, to make searching easier for the operator. Proper training was provided for operators and informed that activities related to knives should be performed before and after the changeover. Next of an indication of, for example, A1, in the storage cabinet, also mentioned the name of the knife.

Fig. 41. Knives storage cabinet

Table 29. Proposed solution searching for knives

A1	B1
A2	B2
A3	B3
A4	B4
…	…

The sixth solution is preparing and bringing to the production line a pick-and-place head and nozzle that will be used in further production. The equipment system indicates what kind of nozzle and head will be used in further production. Operators properly understand what kind of nozzle and head should be brought to the production line and changed during the changeover. To understand where to find information about the changeover standards and training was provided to operators. Where nozzles and heads are located and marked according to the 5S standard and indicated information for operators where the prompter is to understand what nozzle or head will be used. In Fig. 42 a problem is indicated with long search time for a nozzle which should be used in pick-and-place equipment.

After solution implementation as indicated in Fig. 43, an easier way to find a nozzle was suggested, with an indication on the screen of the equipment.

Fig. 42. Nozzle storage

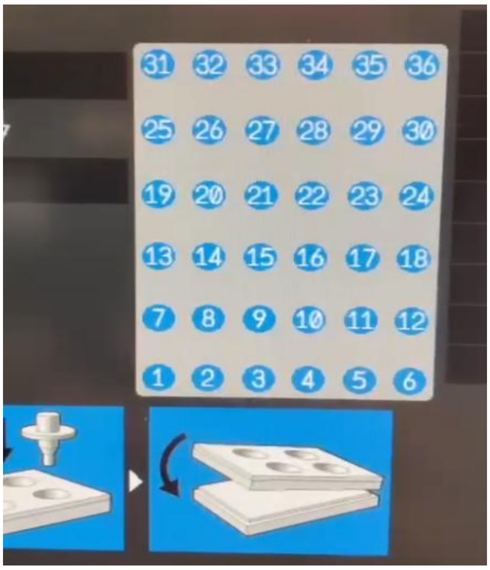

Fig. 43. Nozzle prompter

The seventh solution is the simplest communication between working shifts. The company relies on a simple three-shift per day model. When the one working shift ends their working day - pre-set-up activities should be performed for different altering shifts. As a proposal, communication between shifts is needed so that pre-set-up work for the upcoming shift can be performed in all shifts. Communication is one of the keys to having a well-functioning shop-floor area.

The eighth solution before performing the changeover systematically checks material availability while the previous is still running. Often companies face issues related to lack of materials. Due to that fact, the changeover cannot be carried out, and production will not start. It takes a lot of time to reorient and start performing further changeovers. It was proposed to always check if there is the right number of materials to be used during production. For the eighth solution can also be included that during the changeover only full reels should be ordered from a warehouse and should be prepared before.

In general, all the activities related to walking, searching, and taking back to a production line should be performed before the changeover, to avoid unnecessary walking. Needed tools, equipment, and materials should be prepared when the previous production is still running, to achieve better changeover time. As for activities that should be performed after the changeover application, there are all activities related to placing back all used equipment, tools, etc. into their belongings. Below are indicated a couple of the activities that can be applied after the changeover process:

- Pick-and-place heads should be placed in a suitcase after the performance of a changeover;
- Cleaning and storing knives should be done after the changeover.

To reduce and avoid unnecessary walking activities, a proposal to apply the spaghetti diagram method was implemented. During the changeover operator used a lot of walking, to take tools from their place, bring them back, etc. Fig. 44 indicates how operator walking looked, before spaghetti diagram implementation and application in the shop floor area. Approximately 7 minutes were wasted by performing walking activities. After solution implementation walking activities were decided to perform before and after the changeover. This indicates that the total main changeover duration can be reduced by 7 minutes by performing before and after the changeover. To reduce that time, a spaghetti diagram as a solution was applied. In Fig. 45, it is indicated operator walks after the spaghetti diagram implementation.

Fig. 44. Operators walking before spaghetti diagram implementation

Fig. 45. Operators walking after spaghetti diagram implementation

During the changeover process reduction was always applied 5S method also as a solution. Fig. 46 is the indicated solution to place the cart near the prosecution line with all needed tools, equipment, or materials that will be used during the changeover, to avoid wandering, getting lost, and searching-time during the changeover. The cart was placed according to all 5S standards because most of the time also were lost while searching for needed tools, equipment, or even materials. In that case, the

5S method was applied to get faster, easy to understand, and search for all needed tools for changeover.

Fig. 46. Cart implementation for changeover

After changeover analysis of both SMT production lines and how operators performed changeover – waste activities can be purified. Table 30 indicates the main waste activities that were performed during the changeover and solutions to how those activities could be reduced.

Table 30. Waste indication and solutions how to eliminate it

Waste	**Solution**
The operator does not identify what nozzle will be used in further production after the changeover, in that case, the operator brings the wrong nozzle, which takes approximately 55 seconds. After the installation of the wrong nozzle, the equipment indicated that the chosen nozzle was wrong. The operator performs the second change of a nozzle, and the nozzle is still not the right one. In total, it takes the operator to change the nozzle for approximately 6 minutes and 25 seconds. With the avoidance of mistakes in changing the nozzle, changeover can be reduced by approximately 7 minutes. Searching activities during the changeover.	Pick-and-place equipment on a screen indicates what kind of nozzle is used for chosen production. Not all operators that perform a changeover know this fact. Proper training should be given to operators to show and indicate where the prompter can be seen on the equipment. Searching for all tools that will be used during changeovers should be done before starting to perform changeovers. 5S implementation can help to make searching easier.
Picking up and walking activities, like going to put the old nozzles and heads, searching for a new one, and taking them, takes approximately 1 minute and 55 seconds. It indicates that the unnecessary walking and searching takes a lot of time.	Searching and taking equipment heads and nozzles should be performed before changeover, it can reduce time by 1 minute and 55 seconds. A spaghetti diagram can be applied to identify operator walking activities.
Wrong knives used in solder paste station. The operator uses the wrong knives to apply solder paste on a PCB board. The operator must take them off, search for the proper ones, change the old one for a new one, and scan to see if the knife is correct and installed properly.	As indicated previously, all similar activities should be performed before the start of a changeover. The total time that can be reduced is 1 minute and 15 seconds because it takes approximately this time to perform activities related to knives.

The major waste activities that were indicated in the table below should be eliminated or reduced at all to reach the possible time of the changeover. The activities mentioned are easiest to eliminate and improve the changeover.

Summarized solutions on how to reduce changeover time after SMED implementation are indicated below:

- Requires 5S marking, sequencing, and logic for quick nozzle and head finding;
- Review the operating instructions to see if there are any points about nozzle suitability and selection;
- Support pattern cabinet weights review and adjustment;
- Redesigning feeders to a more convenient option;
- Pre-setup and works – before the changeover and after, include and review work instructions;
- Nozzle and head preparation before the changeover, space or cart required;
- Support pattern marking for easier fixation;
- Magazine preparation for inclusion of the order in the work instruction.

The last solution that can apply for changeover time reduction is related to support pattern activities. The support pattern as mentioned should be brought before the changeover and brought back after the changeover. For operators to find more easily where the support pattern is placed in the storage cabinet, marking in the storage cabinet was provided as indicated in Fig. 47. The idea of how to easily find the support pattern needed for changeovers and production was implemented by marking drawers where they are placed. To find more easily marked not only the name of the support patterns but also the place where it belonged according to the Excel principle. The first-place indication is A1, next to it B1, and so on. Below them, it would be the same, but the number will increase accordingly, as indicated in Table 31. For the operator, it would be easier to find a place to put a support pattern by checking the indicated place but not relying on their name.

Fig. 47. Support pattern storage cabinet with 5S standard

After the implementation of the 5S method, which reduces search time, a solution is indicated in Table 31. Due to the long codes and names of the support patterns, a simpler indication as shown in Table 31 was proposed and implemented.

Table 31. Support patterns storage cabinet with 5S standard

A1	B1	C1	D1
A2	B2	C2	D2
A3	B3	C3	D3
A4	B4	C4	D4
…	…	…	…

3.5. Chapter Summary

In this chapter, the research part of this paperwork was performed. Indication of what impact does SMED method has on the changeover process. The SMED method was applied to two SMT production lines, whose working principle is the same, but they produce different finished products for different customers. The changeover process was applied before and after SMED implementation. The main result of how the changeover process was reduced is indicated. In the beginning, the total average changeover time for the first SMT production line was 14 minutes and 10 seconds and for the second SMT production line, it was 13 minutes 58 seconds. After SMED implementation the changeover over time was reduced for the first SMT production line to 12 minutes 43 seconds and for the second SMT production line to 11 minutes 53 seconds. The changeover process was performed by two different operators, to get better results and in the end to make a comparison between those results. In the end, changeover time was reduced, because of the applied solutions and proper training for the operators.

4. Cost Effectiveness Analysis

At the end of the research, the cost effectiveness analysis needs to be performed to understand how applied SMED method for the changeover process was efficient and how it reduced total costs for the company.

Table 32 indicates how the changeover process duration was reduced during the months of January and February. In the month of January, for both production lines, the changeover process was only analyzed and the SMED method was not applied. In the month of February, the changeover duration is indicated after SMED method implementation for the first and second SMT production lines.

Table 32. Changeover results before and after SMED implementation

Production line	Month	Average changeover time (minutes)	Total changeover time (minutes)	Total changeover number
SMT1	**Total**	**13 minutes 21 seconds**	**2098 minutes**	**154**
	2025-01	14 minutes 10 seconds	1274 minutes	90
	2025-02	12 minutes 43 seconds	824 minutes	64
SMT2	**Total**	**12 minutes 59 seconds**	**3700 minutes**	**289**
	2025-01	13 minutes 58 seconds	2082 minutes	149
	2025-02	11 minutes 53 seconds	1662 minutes	140

Tables 33 and 34 indicate how much it costs for the company to perform the changeover process which was performed on the first SMT production line in the month of January before applying the SMED method. Table 33 indicates the first SMT production line and Table 34 indicates the second SMT production line.

Table 33. SMT1 costs in January

Total monthly downtime (hours)	Personnel downtime costs (EUR)	Equipment downtime costs (EUR)	Total costs (EUR)
21.2	938	1798	2737

Table 34. SMT2 costs in January

Total monthly downtime (hours)	Operator's downtime costs (EUR)	Equipment downtime costs (EUR)	Total costs (EUR)
34.7	1546	3561	5097

Before SMED implementation for the first SMT production line, the total average monthly downtime was 21.2 hours. It indicates that the costs for operators' downtime were 938 euros per month because during the changeover operators were not working and only performed a changeover. The total costs of equipment during downtime before SMED implementation for the first SMT production line were 1798 euros. In total, adding up – the total costs of operators' downtime and equipment downtime total sum is 2737 euros per month and approximately 32 844 euros.

For the second SMT production line, before implementing the SMED method, the total average monthly downtime was 34.7 hours. He incurred 1546 euros in operator downtime and 3561 euros in equipment downtime. In total 5097 euros per month of downtime costs were generated. Calculating costs for one year would be approximately 61 thousand euros.

Results after SMED implementation for both SMT production lines are indicated in Table 35 and Table 36 respectively.

Table 35. SMT1 costs in February

Total monthly downtime (hours)	**Personnel downtime costs (EUR)**	**Equipment downtime costs (EUR)**	**Total costs (EUR)**
13.7	608	1165	1773

Table 36. SMT2 costs in February

Total monthly downtime (hours)	**Personnel downtime costs (EUR)**	**Equipment downtime costs (EUR)**	**Total costs (EUR)**
27.7	1226	2843	4069

After SMED implementation for the changeover process on both SMT production lines, cost reduction can be seen per month. After SMED implementation, in February, the average monthly downtime for SMT1 was reduced to 13.7 hours per month, which indicates that the costs for operators' downtime were 608 euros, 330 euros less than in January. Equipment costs were reduced to 1165 euros per month, 633 euros less than in January, and the total costs were reduced to 1773 euros, 964 euros less than in January for the first SMT production line.

For the second SMT production line, the same results can be indicated. The total average changeover duration was reduced to 27.7 hours. 1226 euros for operators' downtime, 320 euros less than in the month of January. Equipment downtime costs were reduced to 4069 euros, in the month of January the total downtime costs were 5097 euros, which indicated that the total costs were reduced by 1028 euros.

Table 37 indicates how in general the costs were reduced, in effect, by implementing the SMED method for changeover process improvement.

Table 37. Total cost reduction

Production line	**Total monthly downtime (hours)**	**Personnel costs (EUR)**	**Equipment downtime costs (EUR)**	**Total costs (EUR)**
Before SMED implementation SMT1	21.2	938	1798	2737
After SMED implementation SMT1	13.7	608	1165	1773
Before SMED implementation SMT2	34.7	1546	3561	5097
After SMED implementation SMT2	27.7	1226	2843	4069

Table 37 indicates how in general the costs were reduced, in effect, by implementing the SMED method for changeover process improvement.

Fig. 48 is a visual representation of how costs were reduced after SMED implementation for the changeover process for the first and second SMT production lines. Fig. 48 only indicates the total reduced costs, there are not including personnel and equipment downtime costs. Fig. 48 shows before and after monthly costs.

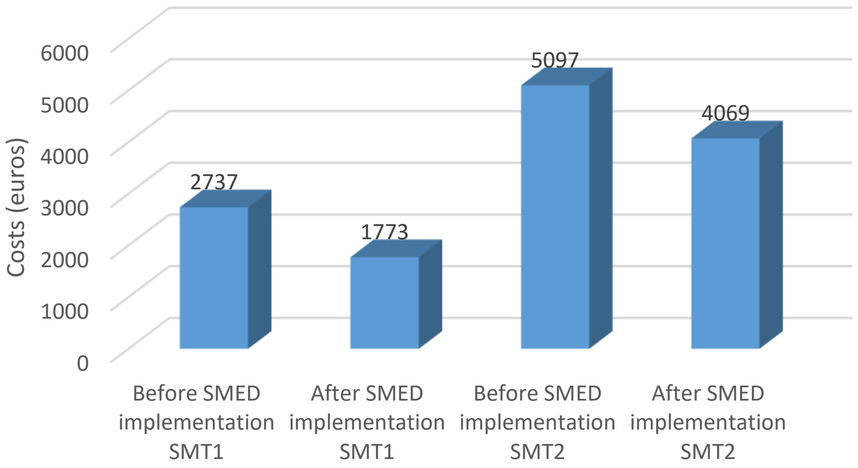

Fig. 48. SMT1 and SMT2 cost reduction before and after SMED implementation

Table 38 indicates how many euros the total cost would be reduced if the total changeover time for SMT1 were reduced from 21.2 hours per month to 13.7 hours and for the second SMT line if the time were reduced from 34.7 hours to 27.7 hours per month. The total cost savings are indicated in the total costs column.

Table 38. Total cost reduction monthly and yearly

Total cost reduction (monthly)				
Production line	Monthly downtime reduction (hours)	Personnel costs (EUR)	Equipment downtime costs (EUR)	Total costs (EUR)
SMT1	7.5	330	633	964
SMT2	7	320	718	1028
Total cost reduction (yearly 2025)				
Production line	Monthly downtime reduction (hours)	Personnel costs yearly (EUR)	Equipment downtime costs (EUR)	Total costs (EUR)
SMT1	7.5	3983	7635	11618
SMT2	7	3718	8620	12338

Table 38, next to the annual column, shows the results of how much money would be saved if the changeover process on the first SMS line lasted 7.5 hours less each month and 7 hours on the second SMT line for a whole year. The total annual cost savings for 2025 are indicated in the total costs column.

Fig. 49 is a visual representation of Table 38, indicating how many euros can be reduced monthly and yearly by keeping the same changeover time for a whole year.

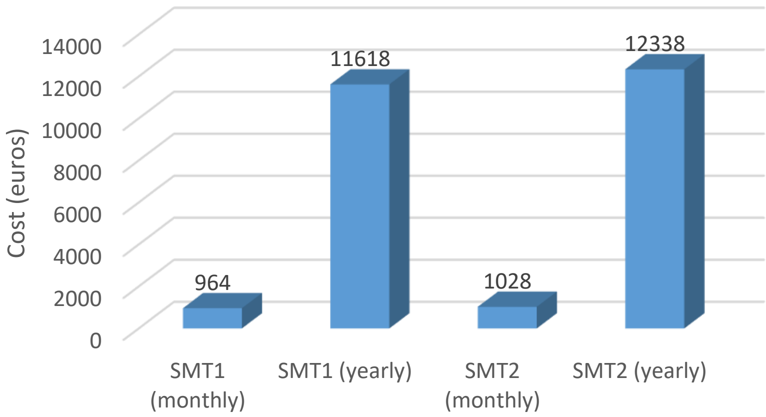

Fig. 49. SMT1 and SMT2 costs reduction monthly and yearly

Finally, Table 39 shows how many euros would be saved each year by reducing changeover time by 7.5 hours for SMT1 and 7 hours for the second SMT production line. Yearly costs would be reduced if the changeover time stayed the same for each changeover applied during each month.

Table 39. Total future cost reduction yearly SMT1 and SMT2

Total cost reduction (yearly) SMT1				
Year	Monthly downtime reduction (hours)	Personnel costs (EUR)	Equipment downtime costs (EUR)	Total costs (EUR)
2025	7.5	3983	7635	11618
2026	7.5	4340	8319	12659
2027	7.5	4340	8319	12659
Total cost reduction (yearly) SMT2				
Year	Monthly downtime reduction (hours)	Personnel costs (EUR)	Equipment downtime costs (EUR)	Total costs (EUR)
2025	7	3718	8620	12338
2026	7	4051	9392	13443
2027	7	4051	9392	13443

Fig. 50 is a visual representation of Table 39, which indicates how total costs would be saved starting from 2025 and ending 2027. Comparing costs saved from 2025 to 2026, cost saving would increase for both SMT production lines, but for 2026 and 2027 costs would stay the same.

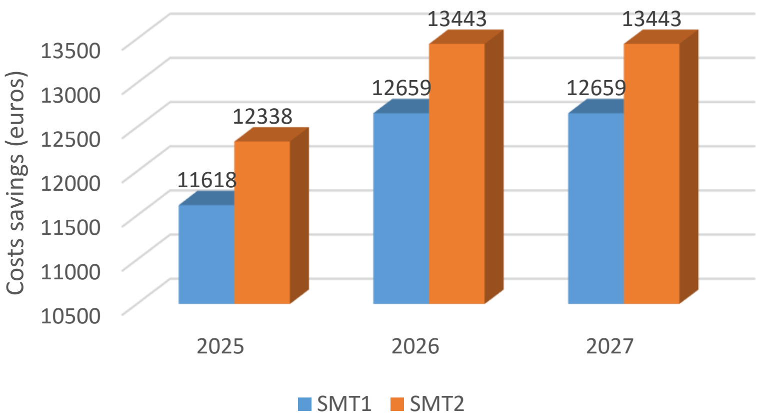

Fig. 50. SMT1 and SMT2 cost reduction before and after SMED implementation (yearly)

4.1. Chapter Summary

In this chapter cost effectiveness analysis was performed to understand how total cost could be saved by applying the SMED method to the changeover process. Calculations were presented in this chapter and indicate how much cost can be saved after SMED implementation in February. In January for the first SMT production line changeover cost was 2737 euros before implementing the SEMD method. For the second SMT production line, it was 5097 euros. For the first SMT production line, costs were reduced by 964 euros to 1773 euros of changeover cost per month. For the second SMT production costs were reduced by 1028 euros to 4069 euros of changeover costs per month. It indicates that the SEMD method implementation was effective according to the cost reduction. Looking at the yearly results for 2025, the total reduction for both SMT production lines could be saved up to 24 thousand euros. For 2026 the total cost saved increased by 2 thousand euros, in total it would be 26 thousand euros. For 2027 the savings would stay the same. In the end, the company for one year, of both production lines, could save up to 24 thousand euros, and that money invested for more important reasons – assets, equipment, materials, etc.

Conclusions

1. Production process management methods that are mostly used were analyzed. 5 LEAN management methods were investigated: 5S, Spaghetti Diagram, Poka-yoke, Kanban, and SMED. Each of the methods brings benefits to production. 5S must be used to standardize the workplace and keep it tidy. The spaghetti diagram detects movements that should be eliminated. Poka-yoke prevents human error possibility. SMED analyzes the duration of the changeover.
2. Changeovers between different products must be efficient, especially in the rapidly fluctuating market. SMED is an advanced method that could be effectively applied in changeover analysis. Positive results were represented in the first example of methodology, by eliminating unnecessary activities changeover duration decreased from 14 minutes and 08 seconds) to 10 minutes and 07 seconds). The second example of methodology indicated that the changeover duration was reduced from 1 hour 10 minutes to 51 minutes per changeover. Therefore, the best solution is to reduce changeover time and to apply SMED method analysis.
3. The SMED method was applied in two Surface Mount Technology production lines. Applied solutions after the SMED analysis brought advantages for the production line. The changeover duration reduced from 21.2 hours to 13.7 hours in the first SMT line analyzed (36%). The changeover time for the second SMT line decreased from 34.7 hours to 27.7 hours (20%).
4. Cost effectiveness calculation was performed. Monthly cost savings for the first SMT line is 964 euros and for the second SMT line – 1028 euros. In total cost reduction per month is 1992 euros. Yearly future analysis was performed; 76 160 euros will be saved until 2027. Therefore, applied solutions reduced the usage of the company’s resources resulting in cost savings.

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