TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

PRODUCTION OPTIMIZATION AT THE AUTONOMOUS SURVEILLANCE SYSTEMS PRODUCER DEFENDEC OÜ

AUTONOOMSETE VALVESÜSTEEMIDE TOOTMISE OPTIMEERIMINE DEFENDEC OÜ NÄITEL

MASTER THESIS

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Tallinn 2021

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Department of Mechanical and Industrial Engineering

THESIS TASK

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Thesis topic:

Production Optimization at the Autonomous Surveillance Systems Producer Defendec

Autonoomsete Valvesüsteemide Tootmise Optimeerimine Defendec OÜ Näitel

Thesis main objectives:

1. Analyse the production flow
2. Identify the production bottlenecks
3. Propose solutions and improvements

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Overview of the company, Literature review	28.02.2021
2.	Actual State Analysis, Concept Development	10.04.2021
3.	Financial Feasibility Analysis	20.05.2021

Language: English **Deadline for the submission of the thesis:** "26" May 2021

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PREFACE

The author initiated this work, who saw the potential for improvement in the current production of Defendec and was interested in contributing to the change. Many other production-related suggestions were made before this master thesis but expanding further during academic work was tempting. Generally, as worldwide competition increases, there will be a greater need for companies to stay competitive. I hope that this master's thesis will provide ideas on how Lean can be implemented in practice.

My thanks go to Defendec OÜ, especially to the head of manufacturing, Mr. Rene Lõhmus, who helped to facilitate my master thesis and enabled me to gather practical experience during my time in Estonia. From the first day, he took his time to answer questions, made suggestions, and provided information.

Furthermore, I would like to express my gratitude to my supervisor Professor Kristo Karjust, who made this master thesis possible, contributed with his knowledge and ideas for improvement.

Finally, I would like to thank my family and friends, who have always supported me during my studies.

Keywords of this master thesis: production optimization, lean, master thesis

ABSTRACT

The present master thesis was written during the fourth semester of the study program Industrial Engineering and Management at the Tallinn University of Technology. The main objective of this thesis is to detect and solve production-related bottlenecks at the site of Defendec OÜ in Tallinn.

The following points characterize the objective:

- Determining and specifying the production flow under consideration of the workers and workplaces utilization;
- Detecting and solving the bottlenecks under consideration of the lean principles and tools;
- Developing an implementation plan for successfully realizing the proposed solutions;
- Calculating the implementation costs for the proposed solutions.

At the beginning of this study, a company overview is given, which includes the products and the production facility of Defendec in Tallinn. The primary lean manufacturing principles are explained in the next step, and several lean tools are presented. The tools are compared based on their usefulness for the previously mentioned objectives.

After the comparison, the simulation software Arena from Rockwell is used to identify the bottlenecks, which are the warehouse and the packaging area. Proposals are made to optimize the current processes at these locations. For this purpose, the lean tools seven wastes, time and motion studies, and 5S are utilized.

The master thesis’ result is a concept for the warehouse and the packaging area, including proposals for improving and optimizing the current production. Furthermore, an implementation plan is given, and a financial calculation showing the solution’s profitability is included.

The project is of great benefit since the master thesis ensures a considerable reduction in costs and supports the production site optimization for high competitiveness in a global environment.

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1. INTRODUCTION

Defendec OÜ is a small Estonian private limited company developing and producing autonomous surveillance systems for private and business customers. The business itself is growing swiftly, with a production increase of over 100% in 2020 at the facility in Tallinn. Therefore, operative changes are necessary to secure a well-operating production with a minimum amount of waste and high resource utilization. The optimization helps as well to cope with the existing space limitations at the current location.

The main objective of this thesis is to find and solve production-related bottlenecks at the site of Defendec in Tallinn. The following points characterize the objective:

- Determining and specifying the production flow under consideration of the workers and workplaces utilization;
- Detecting and solving the bottlenecks under consideration of the lean principles and tools;
- Developing an implementation plan for successfully realizing the proposed solutions;
- Calculating the implementation costs for the proposed solutions.

The master thesis proceeds as follows to achieve the objectives mentioned above:

Chapter 2 gives a general overview of Defendec OÜ, their products, and the production facility in Tallinn. The subsequent main chapter introduces the lean manufacturing principles introduced by Taiichi Ohno and further developed by other specialists and experts. The following sub-chapter of the theoretical part explains several lean tools. The third subchapter addresses criticism regarding the lean approach before subchapter four evaluates the tools. The evaluation is based on the bottleneck analysis and whether they fulfill the requirements for a detailed analysis. Chapter 4 starts with the production flow and bottleneck analysis conducted by using the Arena simulation software from Rockwell. Two of the bottlenecks – the warehouse and the packaging area – will be analyzed in more detail in the second and third subchapter. In the following chapter, the author proposes for both bottlenecks a new optimized concept with an associated implementation plan in chapter 6. A financial calculation to specify the cost of implementation and prove economic efficiency is performed in chapter 7. The thesis concludes with a summary, where the author presents the achieved results.

2. OVERVIEW OF DEFENDEC OÜ

Defendec OÜ is an Estonian company developing and manufacturing autonomous surveillance systems for private and business customers. The devices use smart dust technology, which is defined as "tiny electronic devices in the form of dust particles, which contain sensors and are used for wireless communication" [1]. All micro-electromechanical devices collect data and send them to a command center, where the data is monitored and analyzed. Therefore, the devices are useable in remote areas. Possible application fields are protecting national borders, critical infrastructure, and private property. The surveillance systems are sold worldwide and can be found in more than 35 countries [2].

According to Estonian law, the company, founded as a start-up in 2006, is a private limited company registered in Estonia and defined as a small undertaking [3]. The company's name was Smartdust Solutions until the business was renamed Defendec in 2010 [4]. Legally, the company's representatives are Tauri Tuubel and Indrek Jaaska [5].

Defendec's headquarter is located in Tallinn. Subsidiaries are located in the United Kingdom as well as in the United States of America. The company is steadily growing with a revenue of over 2,7 Million Euros in 2020. Table 2.1 displays the revenues and operating profits for the last ten years.

Table 2.1 Defendec's Financial Performance

Year	Revenue (k€)	Operating profit/EBIT (k€)
2010	206	37
2011	340	-504
2012	658	-396
2013	1.010	-625
2014	2.144	465
2015	978	-671
2016	2.164	318
2017	1.543	-687
2018	669	-673
2019	1.903	-39
2020	2.759	-70

The annual revenue over time is increasing. However, large jumps occur due to the unstable and volatile international defense industry market, where large-scale orders and fluctuation in demand are common. The sale process for each partly customized project takes up to several years. The financial performance in 2018 is explainable by a strategy change, which occurred in that year. Defendec expanded into the private security market, which is less volatile and based on smaller orders than the defense industry. Since then, the annual production has doubled, and the overall revenue has increased to an all-time high. However, the operating profit is primarily negative due to high investment costs spent for research and development as well as for entering new markets. Even though Defendec generated a minor operating loss during the last two years, the company is in a good position because sister companies sell all manufactured products. Therefore, the company group generates a positive profit.

As already mentioned, Defendec is active in two different markets – the defense and border guard sector and the private security sector. The first product is Smartdec, a product developed for the Estonian Police and Border Guard. Since then, many European Union and NATO nations use the product to protect their borders. For example, Smartdec devices are installed at the Estonian-Russian border. The surveillance system helps to prevent illegal border activities and unauthorized border crossings. As already mentioned, the market is very volatile, and sale processes for customized solutions take years. Furthermore, public procurement processes must be followed to win tenders. The offered solutions sell for a one-off purchase price.

The second product – ReconEyez – exists since the strategy change in 2018 and focuses on private customers mainly located in the United Kingdom and Western Europe. The subsidiary in the United States set up to enter the North American market. ReconEyez devices are used for property protection and prevent illegal trespassing and burglary. Possible application sites are construction, energy, and mining plants. The market is price sensitive and based on short delivery times.

Furthermore, customers expect low operating costs and a high automation level to reduce labor. ReconEyez's business model rests upon a monthly subscription for renting the devices and, if needed, the server capacity to run the system. Therefore, the cash inflow is more stable and easier to forecast. In general, the management expects a high growth potential in the commercial market. Currently, 90% of the devices are exported, which is a good indicator of the product's scalability. In addition to distributing ReconEyez through foreign contractors, Defendec is setting up offices abroad for direct distribution. As of February 2020, the software is available in Estonian, Russian, English, French, German, and six other languages.

Defendec is divided into four departments according to the company’s primary functions, which Figure 2.1 illustrates.

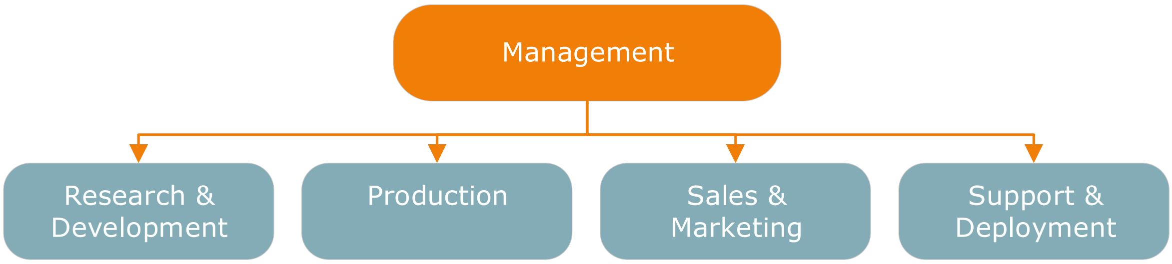

Figure 2.1 Defendec’s Company Structure

Research and development include hardware and software development for the two main products Smartdec and ReconEyez. The production department includes purchasing as well as ensuring the quality of the product. Furthermore, they are responsible for the warehouse operations and shipping. In total, the company has 27 employees[1]. KPIs and objectives, which must be reached in a specific period, measure the performance of each department.

2.1 Product Overview

2.1.1 System Overview

ReconEyez is a visual surveillance system with the following main components: detector, bridge, and command center. In addition, the property owner can install sirens for an acoustic and visual alarm at the surveillance area. Figure 2.2 illustrates the working principle.

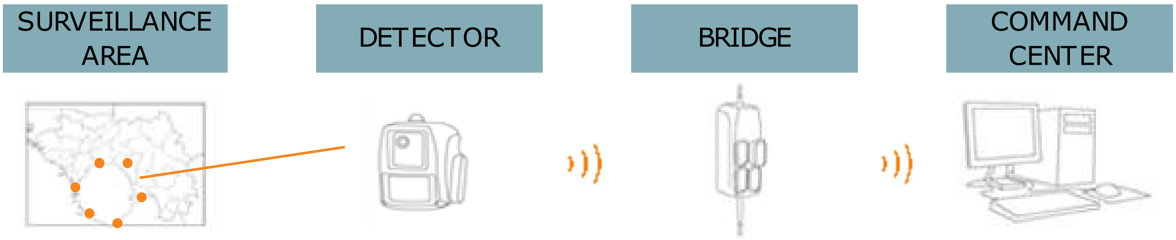

Figure 2.2 System Overview of the ReconEyez system [6]

[1] As of 10.02.2021

Several detectors are in the surveillance area, which will take a picture if they detect something. Afterwards, the bridge forwards the detector data to the command center, where they manage the alarm and activate countermeasures. The mentioned devices – detectors, bridges, and sirens – can be installed and configured within several minutes [7].

Defendec develops and produces all devices in-house or in cooperation with some subcontractors according to ISO 9001:2015. Besides the main products, accessories are included and delivered to the customers. The main accessories are [8]:

- Solar panels for recharging the batteries at remote sites;
- Battery extension packs;
- Battery charger;
- Handheld devices;
- Fastening accessories (screws, brackets, etc.);
- Security accessories (hex pint bolts, security nuts, etc.).

The devices are manufactured out of resilient materials and are conforming to military standards. Their ingress protection code[1] is 67, claiming that the device enclosures are dust-tight and waterproof under one meter of water for 30 minutes. The ingress protection code is vital because the devices are installed in outside areas and exposed to wind, rain, snow, etc. The temperature range for operating the devices is between −40° Celsius and +60° Celsius.

10,2 Ah lithium-ion batteries ensure the power supply. They are exchangeable and rechargeable, and when fully charged, power the devices for about 400 days. However, the device’s runtime varies depending on the following factors:

- The signal quality;
- The image quality;
- The number of events detected and sent.

The runtime without battery exchanges can be prolonged using battery extension packs or solar panels, eliminating the necessary battery exchange if enough energy transforms. Furthermore, all devices are equipped with theft protection, informing the command center if they are moved or touched. If a bridge or siren cannot directly reach the bridge, other devices receive the data over a low-power mesh network and send it to the command center.

[1] The ingress protection rating is used to rate the protection or sealing effectivness in electrical enclosures against intrusions of water, dust or other objects. The rating is described in the European standard EN 60529.

2.1.2 The detector device

As depicted in figure 2.3, the detector is an autonomous sensing device to detect motion and temperature changes in front of the detector by utilizing a passive infrared sensor. The detector can take pictures during the day and night in Full HD. However, the resolution of the day camera is slightly higher. In case of an alarm, the photo is taken within 0,5 seconds after the alarm is triggered. The detector transfers the pictures to the nearby bridge via a 2,4 GHz radio module. The product's size is about 85 x 120 x 100 mm and weighs 0,7 kg [8].

Detection Range:	30,5 meters
Picture:	Full HD
	Day and Night Camera
	Infrared Flash
Battery:	rechargable Li-ion
	up to 400 days stand by
Radio:	800 m line of sight
	2,4 GHz, bandwidth 250 kbps
Temperature:	-45 °C up to +60 °C
Size:	8,5 cm x 12 cm x 10 cm

Figure 2.3 Detector Device [6]

2.1.3 The bridge device

The bridge is a communication device that facilitates two-way communication between detectors and command centers. Figure 2.4 displays the product with additional technical parameters. One bridge supports up to eight detectors or sirens connected via a 2,4 GHz short-range radio. Command centers are reached via GSM signals. The product's size is about 95 x 75 x 295 mm (without the antenna) and weighs 1,4 kg [8].

Long range radio:	
Battery:	rechargable Li-ion
	up to 150 days stand by
	or up to 50.000 incidents
Radio:	800 m line of sight
	2,4 GHz, bandwidth 115 kbps
Temperature:	-45 °C up to +60 °C
Size:	9,5 cm x 7,5 cm x 29,5 cm

Figure 2.4 Bridge Device [8]

2.1.4 The Siren device

The siren is an audible and visual alarm indication device for the protected area. Figure 2.5 shows the product's visual appearance and some technical specifications. The operator from the command center activates the sirens. The main goal is to scare off and warn any intruder using the siren's beacon and the alarm with over 90 dB(A)[1] [9]. The siren is based on the bridge enclosure but without a GSM-Antenna. Therefore, the device cannot directly communicate with the command center. The properties are similar to the bridge with a size of 95 x 75 x 360 mm and a weight of 1,5 kg [8].

Indication Device:	Max 102 dBA
Siren tone:	Sweep or steady
Tone frequency:	2400-2800Hz
Battery:	rechargable Li-ion up to 400 days stand by or 200 hours of constant alarm
Radio:	500 m line of sight 2,4 GHz, bandwidth 115 kbps
Temperature:	-45 °C up to +60 °C
Size:	9,5 cm x 7,5 cm x 36,0 cm

Figure 2.5 Siren Device [8]

2.1.5 The Command Center

The command center collects and stores received information from the field devices. A secure web-based user interface allows having an unlimited number of command centers and users [6]. Depending on the user's job, his rights and permissions within the user interface are individually configurable. The main features of the user interface are [10]:

- An alarm and event overview;
- Signal quality and data traffic information;
- Remote device configuration;
- A map with all device locations;
- Managing user and administrator rights;
- Statistics about the system and the devices.

[1] Measurment distance 1m

2.2 Introduction of the Production Facility in Tallinn

Defendec's production unit and the warehouse are located on the second floor of the Arsenal Center in Tallinn. The employees must carry all components upstairs using the staircase because there is no elevator available. The final products are passed downstairs again, where logistic providers pick them up. The distance between the entrance and the production and warehouse area is approximately 50 meters.

As of March 2021, Defendec employs three full-time employees and several production helpers, all lead by the production manager. The primary duties of the production manager are planning and scheduling the weekly production. Furthermore, he is responsible for the supply chain, is in close contact with all the national and international suppliers, and manages all production-related inquiries. One employee, the production assistant, supports the production manager, works on the necessary documentation, organizes final product shipments, and oversees the warehouse. The other two full-time employees are production specialists capable of producing and assembling the devices from start to finish. They are responsible for assembling, testing, and packing the devices. If the demand is higher than their output, several production helpers who work part-time at Defendec support them. They are mainly working in the evening or on the weekend, making it possible to maximize workplace utilization.

The current production is organized according to the assemble-to-order principle because each device includes a customer-specific security certificate. Therefore, it is not possible to follow the make-to-stock principle. Make-to-order is less suitable because lead times would increase [11], which contrasts with the short delivery times set by the customers and the market. The three products are produced separately in batches but share some of the workstations. The batch size itself is not fixed and depends on customer orders, incoming supplies, and available worker capacity.

The space allocation evolved naturally and is lacking a plan at which workspace a specific task is performed. The necessary equipment for each job is stored near the workplace, where employees previously carried out the job. As a result, the workplaces are not explicitly defined but are commonly used for the same tasks. Only some jobs are always performed at the same workplace because they are bound to special tools like testing stations. Figure 2.6 displays the overall layout of the production and the warehouse.

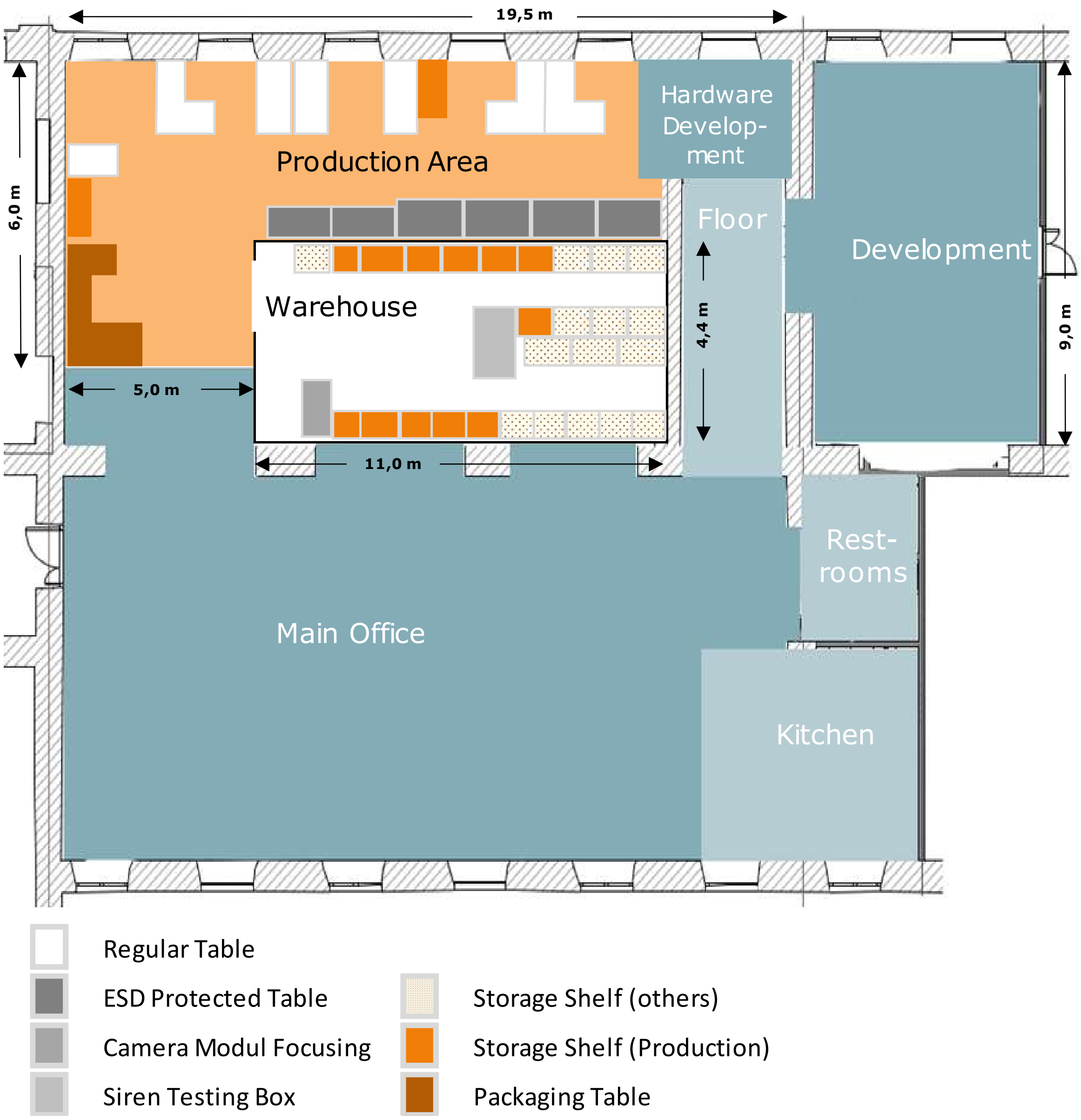

Figure 2.6 Layout of Defendec's Facility in Tallinn

As shown in the layout plan, the production area is next to the office area and occupies approximately 80 square meters. The warehouse is a smaller room of 48 square meters directly connected to the production area. All production-related components are stored within 12 shelves. In the back, Defendec's other departments have space reserved for them. Work-in-progress is stored on tables, shelves, or on carts within the production room. The production includes several ESD[1] tables, where PCBs[2] are handled. In

[1] ESD is the abbreviation for "Electro Static Discharge" and is caused by the exchange of charge between two bodies with different voltage potentials and can damage electronic components used in the production.

[2] A printed circuit board is a carrier for electronic components and is used for mechanical fastening as well as an electrical connection of the components.

addition, the floor material is made from ESD protective material, and employees have to wear ESD footwear. If those measures are not applied, electric components might be damaged and must be replaced. The desks along the window facade are private and belong to single employees, while most production tasks are performed on the opposite site at the already mentioned ESD table. In the lower-left corner, the packaging area is located.

Defendec is certified according to ISO 9001:2015 [2], which specifies the minimum requirements for a quality management system that an organization must meet to provide products and services that meet customer expectations and any regulatory requirements [12] [13].

3. THEORETICAL BACKGROUND

3.1 Lean Manufacturing Principles

Taiichi Ohno, a former employee of Toyota, developed lean manufacturing and published it in 1988 in his book "Toyota Production System: Beyond Large-Scale Production". Lean manufacturing is derived predominantly from the Toyota production system and created to compete with the American mass production. Toyota had a competitive disadvantage because their sales market was minor compared to the American, and therefore the imitation of the American style was dangerous. Instead, Taiichi Ohno focused on an independent model that was "geared to inexpensive limited production of a large variety of models" [14].

Consequently, lean manufacturing aims to produce goods more efficiently, which can be achieved using fewer materials, tools, machines, workers and reducing production time [15]. Today, lean manufacturing is an effective and widely used tool in most manufacturing industries and the service sector to reduce or eliminate non-value-adding activities [16]. Taiichi Ohno stated clearly in his article that:

> "Our products have to pass muster on the free market, where they are subjected to the critical eye of the consumer. He is not interested in how much it costs to produce a product but in whether or not the product is of value to him" [14].

According to this principle, every working process can be specified as Value Added, Required Non-Value-Added, or Non-Value-Added. Value-Added activities conform to the following three conditions [17]:

- The process transforms information or material;[1]
- The customer is willing to pay for the process;
- The process is done correctly on the first attempt.

Required Non-Value-Added processes do not conform to the previously mentioned conditions. However, they must be fulfilled and are specified by law, company policies, or other contracts. Even though those processes cannot be eliminated, they should be reduced to streamline manufacturing [18].
The latter category, Non-Value-Added processes, do not create any value but consume resources. Therefore, they are wasting company resources and need to be eliminated.

[1] This does not include tasks like transporting goods from A to B, because they are not transformed by themselves.

3.2 Lean Tools

Over the last decades, various lean tools were created to reduce or eliminate non-value processes. Companies can maximize capacity utilization, reduce manufacturing times, inventory, and many other essential factors by utilizing lean tools [19]. An overview of the various lean tools can be seen in Figure 3.1. Short explanations for the mentioned tools can be found on the following pages.

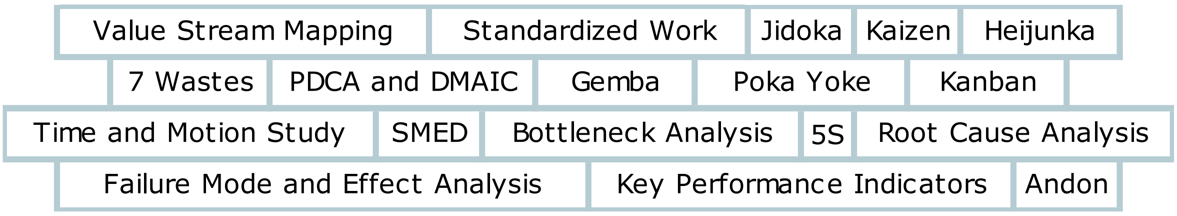

Figure 3.1 Overview of the explained Lean Tools

<u>7 Wastes</u>

The seven wastes describe types of non-value-adding in business and manufacturing, which the Japanese call Muda (waste). Fujio Cho, the former CEO of Toyota, defined waste as:

> "anything other than the minimum amount of equipment, materials, parts, space and worker's time, which are absolutely essential to add value to the product." [20]

The first step to reduce or eliminate waste is to ask: What would the customer[1] like to get out of the process? Later, Jeffrey K. Liker added an eight waste in his book "The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer" [21]. Table 3.1 lists all eight types with a short explanation.

[1] The meaning customer in this case includes internal customers e.g. employees from another department.

Table 3.1 The Eight Wastes of Lean [21] [22]

Type of waste	Description
Transport	Moving the product or material from one place to another, some transportation is necessary to transfer parts for processing.
Inventory	Excess inventory hides production problems (late deliveries, defects, machine downtimes, etc.), binds capital and needs storage space.
Motion	Any movement by an employee that is not as short or easy as possible; e.g. searching for tools, reaching for something, long walking distances, etc.
Waiting	Employees have idle time because they are waiting for a machine, supplies or are restricted by delays of any sort.
Overproduction	Manufacturing products without orders, which might not be sold due to lack in demand and creating access inventory.
Overprocessing	Performing processing that is not necessary to achieve the customers requirements and therefore does not add value, which is valued by the customer; e.g. providing higher-quality products than ordered.
Defects	Production of defective parts, which have to be reworked or replaced. In any case material and time is wasted and the customer's delivery date might be affected.
Skills	Skills, expertise and talent of the employees that is not utilized by the employer.

In conclusion, the seven wastes help to reduce and eliminate waste, which has a positive impact on the following areas of improvement [22]:

- Higher customer satisfaction;
- Lower inventory level;
- Fewer machine breakdowns;
- Higher machine utilization;
- Improved manufacturing efficiency;
- Fewer defects and rework;
- Increased profitability.

Key Performance Indicators

The term Key Performance Indicator (KPI) refers to crucial figures used to determine the performance of activities. KPIs enable companies to measure some aspect and compare it with a predefined target. For a consistent KPI system, the following principles should be followed [23]:

- KPIs must be measurable;
- KPI factors must be controllable;
- KPIs must be attainable;
- KPIs must promote the correct course of action;
- KPIs must be meaningful to all parties.

Gemba

The concept of Genchi Genbutsu, also known as Gemba, means to observe at the actual location. The actual location describes the place the tasks and processes occur, which is commonly the shop floor. Each process or workflow is examined for a better understanding of how it can be optimized. In general, the method encourages all employees to be creative and innovative [21] [24].

Jidoka

Jidoka roughly translates to "autonomation with a human touch" and describes a partially automated process that stops automatically when a defect is detected [24]. Employees can monitor multiple workstations at a time, and a zero-defect strategy is followed [20].

Andon

Andon is a simple visual signal in the Toyota Production System. A signal lamp on a machine is intended to draw attention to irregularities and interruptions in the production process [14]. Andon is thus one of the central elements of Jidoka, the human-facing automation, and hence the principle of immediately interrupting work when a problem occurs [25]. Over time, it became a visual management method with self-explanatory symbols, for example, by using the colors red, yellow, and green to indicate the current operating status of a machine or a production line in a way that is immediately recognizable to everyone. Therefore, Andon is a visual or even acoustic information system with a central display of the problem location if a fault is detected [26] [21].

Poka Yoke

The term Poka-Yoke was introduced by Shigeo Shingo [27]. It describes a process or device that is foolproof for humans and machines [28] [29]. It serves to prevent (yoke) any mistake (poka) a worker can make [27].
A practical application, for example, is positioning sensors on a press, which do not allow the process to start until the component is correctly inserted.

5S

The Japanese words seiri, seiton, seisou, seiketsu, and shitsuke are commonly referred to as 5S. Figure 3.2 displays the English translation and its implementation order.

Figure 3.2 Overview of the 5S

The method is used to achieve clean, organized, standardized, and manageable workstations and manufacturing areas [17] [30]. The objectives of 5S implementation in more detail are [31] [32]:

- Reduce waste and non-value-adding tasks;
- Increase the workers' efficiency;
- Eliminate unnecessary activities;
- Increase the product quality;
- Decrease the manufacturing cost;
- Increase the security and safety;
- Improve the working environment.

Table 3.2 explains what must be done in each step to reach the previously mentioned objectives.

Table 3.2 Explanation of the 5S [21]

Step	Description
1 - Sort	Sort through items and keep only what is needed while disposing of what is not.
2 - Set in order	A place for everything and everything is in place
3 - Shine	The cleaning process often acts as a form of inspection that exposes abnormal and pre-failure conditions that could hurt quality or cause machine failure
4 - Standardize	Develop systems and procedures to maintain and monitor the first three S
5 - Sustain	Maintaining a stabilized workplace is an ongoing process of continous improvement

Kaizen

Kaizen is the Japanese word for improvement and describes a management philosophy of constant improvement to eliminate waste [33]. The product or process improvements are mostly minor changes, which add up together to increase productivity over time. A radical change, in turn, is referred to as kaikaku in Japanese and requires most often significant investments and cannot be implemented shortly [26].

Time and Motion Study

A time and motion study is the observation of physical movements involved in performing a job. In addition, how the movements can be made more effective and cost-efficient is investigated [34]. The goal is to reduce or eliminate non-value-adding activities [26]. In a recently published study, D. R. Kiran named four fundamental factors influencing a worker's productivity [35]. Figure 3.3 gives a graphical overview of the factors.

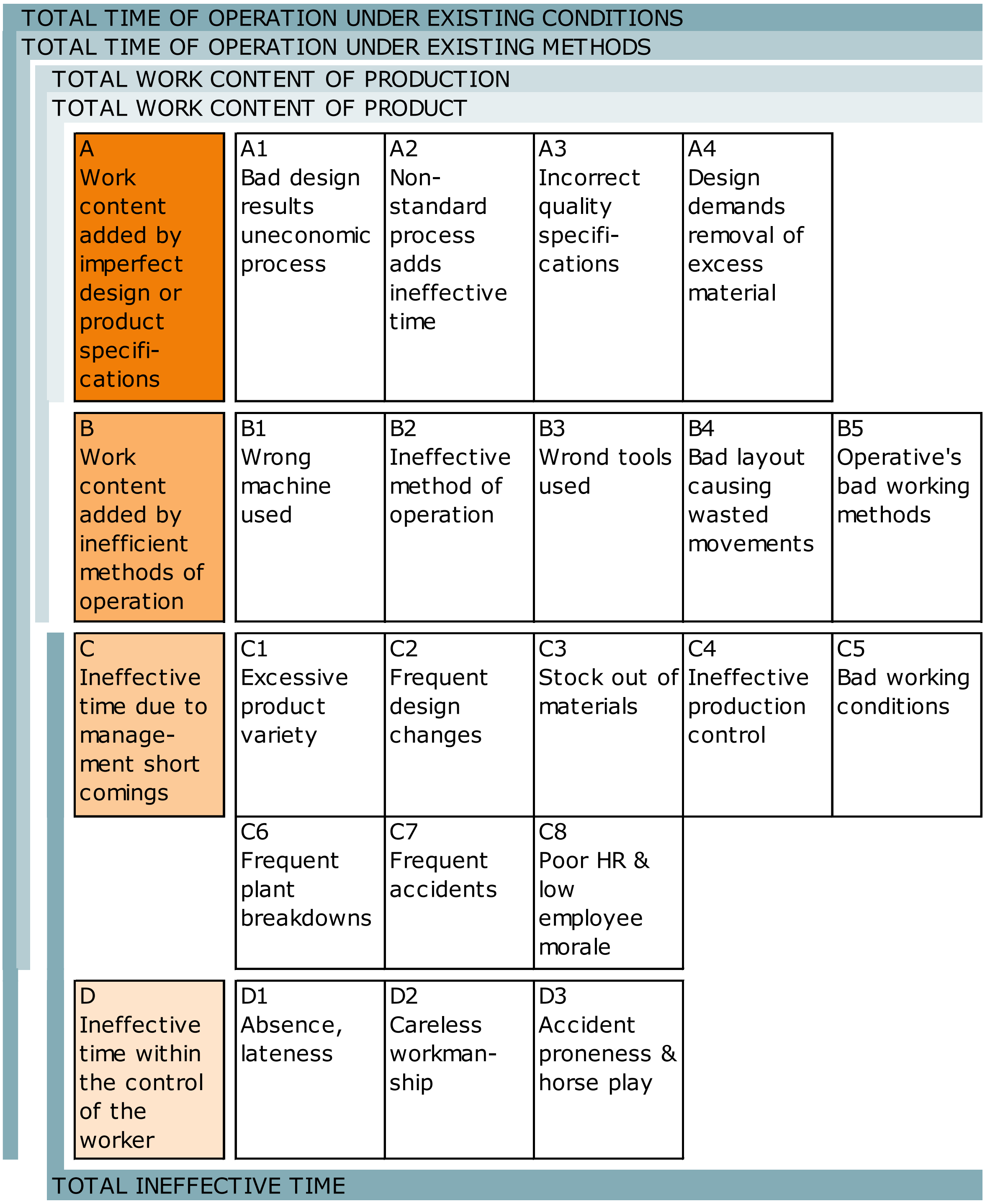

Figure 3.3 Factors influencing the worker’s efficiency [35]

<u>SMED</u>

The abbreviation SMED stands for Single Minute Exchange of Die and refers to tool changes in the single-digit minute range. Shigeo Shingō developed the methods as a part of the Toyota Production System [36]. This method shortens setup time through organizational and technical measures. It aims to set up or reconfigure a machine or a production line within one manufacturing cycle, leading to minimum delay and avoiding waste [26] [37].

Bottleneck Analysis

In business, a bottleneck is an organizational weakness that has the highest capacity utilization in the entire process chain in each period and thus impedes the workflow. As a result, the bottleneck dictates the production throughput. Balancing the workstation cycle times or adding additional machines, generating a higher output together, can solve the problem [11].

Heijunka

The term Heijunka, which originates from Japanese, can be translated as “smoothing” or “leveling”. In lean management, Heijunka stands for “production smoothing” or “leveled production” and refers to a work planning method developed at Toyota in the 1950s. The aim is to harmonize the production flow by balancing the incoming and outgoing elements in the production line to avoid queues and waste due to idle and transport times. After the redistribution of work, every operator should have the same workload [38] [39].

Root Cause Analysis

The idea of the root cause analysis is to identify and eliminate the root cause or hidden source of the problem instead of just treating the symptoms. Therefore, the basic idea is to describe the issue or symptoms as precisely as possible, narrow down the potential sources of the problem, and then follow the error path [39]. Generally, there are several different methods, which can be used to track down the root cause. Two of them, the 5 Why method and the cause-effect diagram, will be explained by the author.

The 5 Why method uses several “why” questions when searching for the root cause of the problem. The number of follow-up questions is not limited to five; this number is to be understood symbolically. It is important to follow up until the process step causing the error is identified and can no longer or further be split up [21]. Taiichi Ohno explained the method in his book about the Toyota production system by investigating a machine breakdown, as shown in Table 3.3.

Table 3.3 5 Why Example from Taiichi Ohno [40]

Question	Answer
Why did the machine stop?	There was an overload and the fuse blew.
Why was there an overload?	The bearing was not sufficiently lubricated.
Why was it not lubricated sufficiently?	The lubrication pump was not pumping sufficiently.
Why was it not pumping sufficiently?	The shaft of the pump was worn and rattling.
Why was the shaft worn out?	There was no strainer attached and metal scrap got in.

The problem is likely to reoccur within a few months if the path is not pursued until the root cause.

The second method is the cause-effect diagram, often referred to as the Ishikawa diagram after its inventor Kaoru Ishikawa [38]. The simple construction of the Ishikawa diagram starts from an undesired result and retrospectively asks questions about the leading causes, which in turn have influencing parameters. With the help of the Ishikawa diagram, situations can be analyzed, and interdependencies among them can be identified [38]. It is commonly used as a problem-solving technique in team meetings. In the first step, the team members collect available process knowledge among them in a brainstorming session. Then they group the potential causes into main causes according to logical criteria. The graphical representation makes it easier for the team to uncover problems and problem areas that might have remained undiscovered with a different approach.

Figure 3.4 shows an example of a cause-effect diagram. The example is based on a company performing emergency service for their heating systems at the customer's place. Regularly, the engineers were missing out on spare parts to solve the problem on their first visit. Therefore, the reasons for unscheduled returns were tracked for 12 months and afterwards grouped according to five main points. Based on the Ishikawa diagram, the company decided to solve the problem by improving the information flow for the engineers, which helped them predict the cause more frequently and precisely [11].

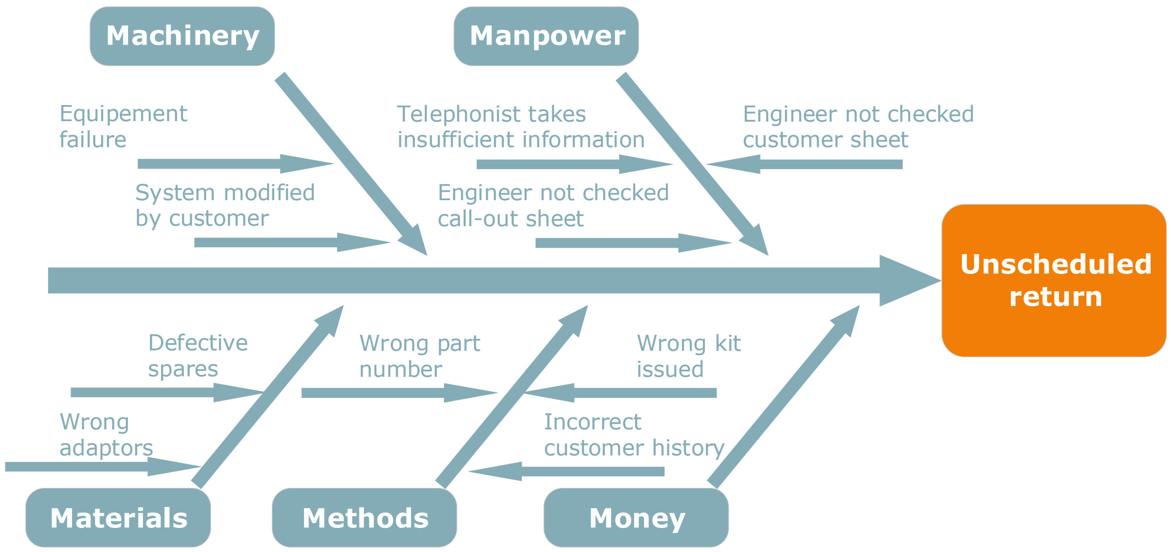

Figure 3.4 Ishikawa Diagram [11]

Failure Mode and Effect Analysis

A well-known tool for quality improvement in all value chain phases is the Failure Mode and Effects Analysis (FMEA). FMEA can be applied to products as well as processes. It is a method to identify potential failures and classifying them in terms of their impact on the product development, product, process, or system [41].

The analysis is based on answering the following three questions [11]:

- What is the likelihood that failure will occur?
- What would the consequences of the failure be?
- How likely is such a failure to be detected before it affects the customer?

The three questions are each graded with a risk assessment number and multiplied to obtain the risk priority number. The most severe risks can be addressed after the calculation. The goal is to prevent failures, limit the adverse effects, and prepare countermeasures if a failure still occurs.

Standardized Work

Standardization of work processes means determining the best possible sequence of a recurring activity and documenting it. The standardization "helps to maintain consistent quality, provides efficient operations, and ensures the proper use of tools and equipment" [42]. Workers need the training to detect waste and reduce nonvalue tasks. If the work process is efficient, it can be implemented across the employees and promoted as the best practice.

When planning to standardize work, it is crucial to start with the work improvement[1] before the equipment improvement can occur, based on the best practice. The manufacturing process can be improved by following this order, and most problems can be eliminated, according to Taiichi Ohno [40]. Furthermore, standardization is necessary when implementing just-in-time production.

Value Stream Mapping

Value stream mapping is a common approach in lean management to optimize value creation and minimizing waste. The first step is to map the materials and information flow through the company during production from the customer's perspective because the customer determines the requirements for production and all involved processes [43]. The value stream is recorded, evaluated in terms of time, and visualized in the form of a flow diagram with simple, standardized symbols[2] [21] [44]. In Figure 3.5, an exemplary current state value stream is displayed.

[1] E.g.: Establishing standards, redistributing work and defining workplaces.

[2] A detailed overview and explanations of all symbols can be found in the book „Learning to See: Value Stream Mapping to Create Value and Eliminate Muda" by Mike Rother.

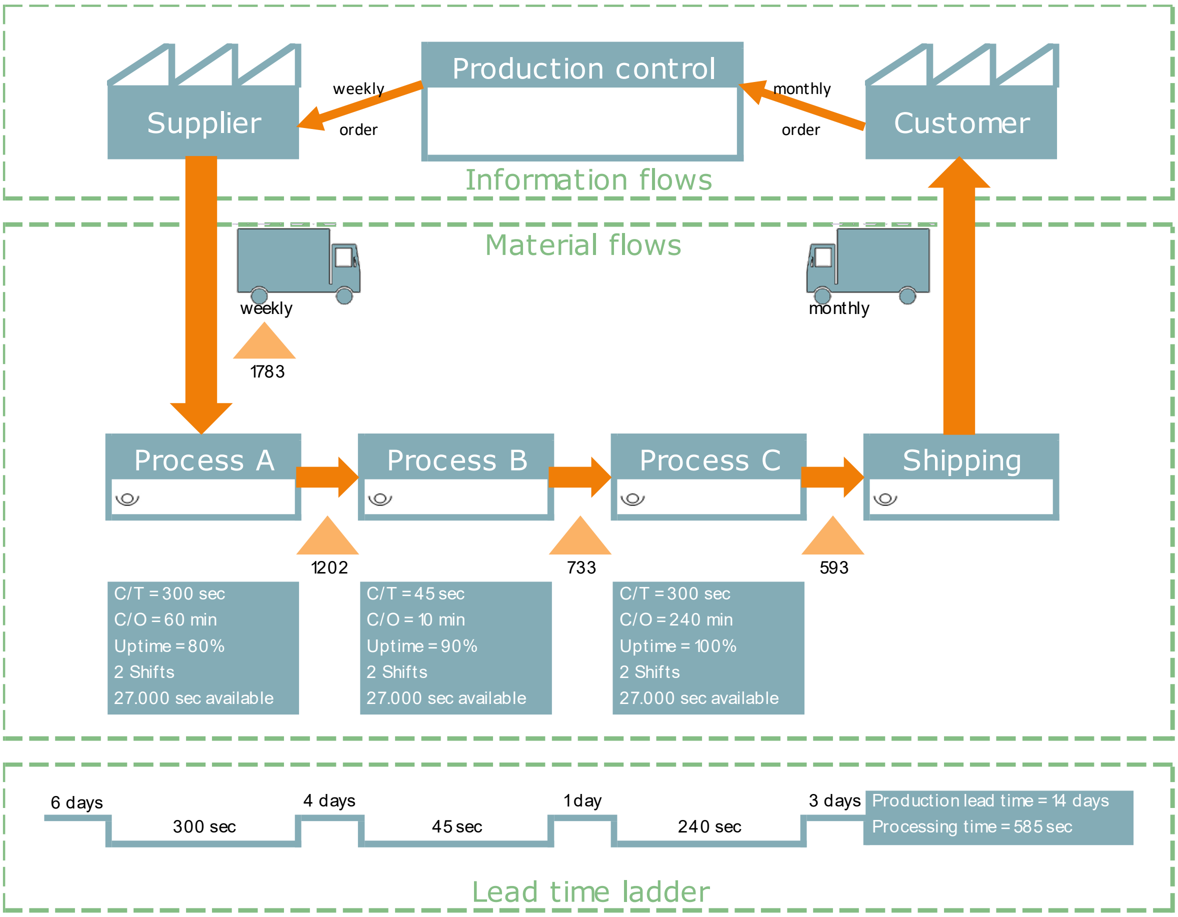

Figure 3.5 A Current State Value Stream Map

The value stream comprises all process segments and activities, including value-adding primary activities and non-value-adding support activities. The process evaluation criteria and starting points for improvement are the proportion of non-value-adding activities, the order throughput time, and the proportion of processing time in the throughput time. The assessment is being done on an ongoing basis to enable continuous improvement of the process steps.

<u>Kanban</u>

The term Kanban comes from the Japanese and means card or label. Developed by Taiichi Ohno, the inventor of the Toyota production system, Kanban is implementing the pull production flow between workstations [28]. It was inspired by the procedure in supermarkets [40], where consumers serve themselves and employees ensure sufficient stock on the shelves depending on the outflow of goods. Once employees replenish the racks, the cycle begins again.

The basic principle of Kanban is the organization of multistage production processes in the form of interlinked control loops. Each of these control loops consists of a production stage and an upstream material store. For each production process, the employee takes the currently required material quantities from the corresponding material warehouse. Shortages are replenished by the upstream production stage independently. The same applies to each operation, as in each case, a downstream operation takes from an upstream operation only the part currently required in the required quantity and at the required time [21]. The procedure is based exclusively on the actual consumption of materials [45].

While the material flow moves from the starting material to the final product, the information flows in the opposite direction in the form of physical or electronic cards that document and report back the withdrawal and production of materials at each stage.

In this way, a self-organizing system is created that minimizes inventory, enables faster throughput times, optimizes the utilization of manufacturing capacity by considering the current bottleneck at any given time, and thus reduces waste [45] [46]. Therefore, value creation can be optimally controlled at each manufacturing stage in the system.

PDCA and DMAIC

PDCA and DMAIC are methods for solving problems and improving processes constantly [47]. Both describe problem-solving cycles within several steps, explained in detail in Figure 3.6 and Figure 3.7.

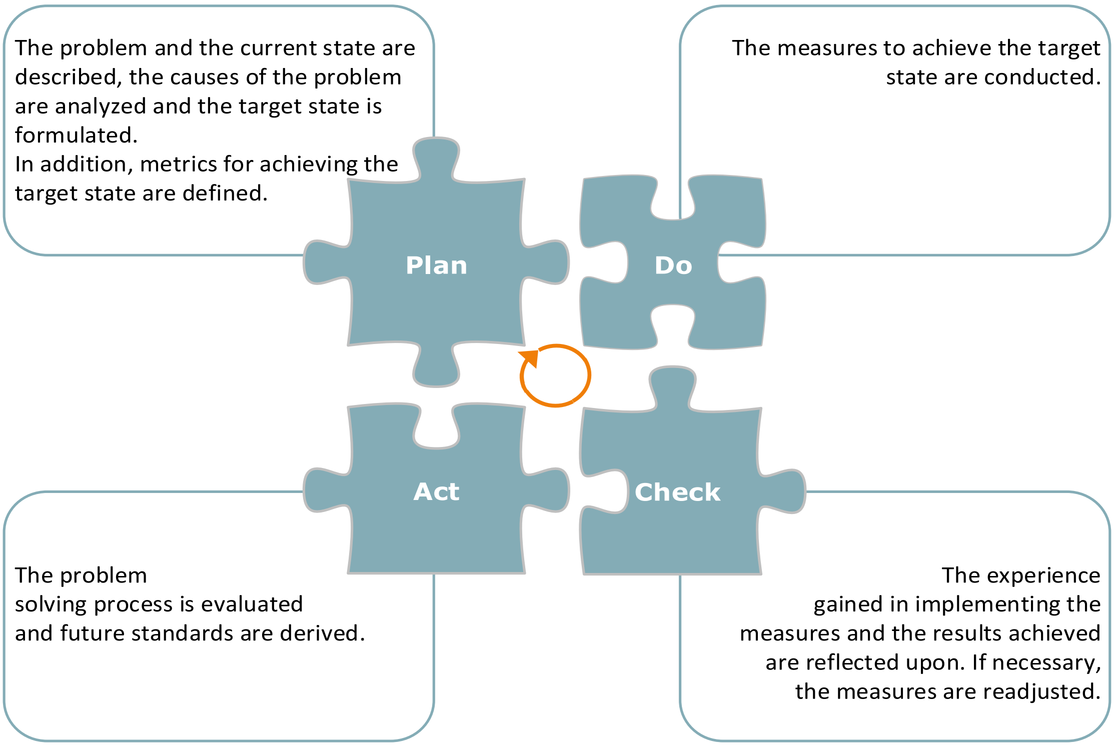

Figure 3.6 Overview of the PDCA Cycle [38] [48]

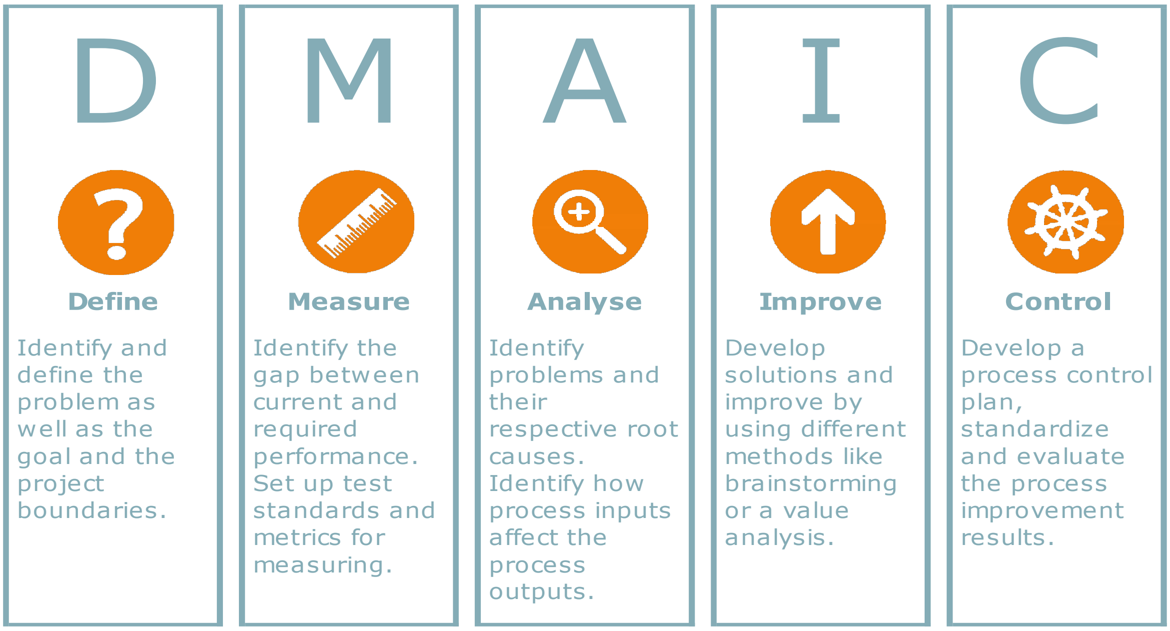

Figure 3.7 Overview of the DMAIC Cycle [38]

3.3 Lean Criticism

Critics regarding the Lean approach started when it became popular, and companies worldwide started to implement Lean. A study by Hines, Holweg, and Rich summarizes and gives an overview of the academic criticism between 1980 and 2000. The main point of criticism over the last decades is the evolution and expansion of lean as a manufacturing management tool [49], even though the concept was initially created only for production [50] and had a narrow definition around shop-floor improvements. However, many critics did not account for the change of Lean over time [49].

Richard Cooney adds to the criticism that outside factors like the market situation are not considered during lean implementation, even though those external factors influence the business and should be included. In his paper, he writes:

> "Lean production is dependent upon production leveling throughout the whole supply chain to achieve just-in-time flow and without this precondition being met the utility of lean factory practice is called into question." [51]

A study by Bhasin and Burcher calls the low successful implementation rate of Lean[1] into question and identified the following difficulties companies face when implementing lean [52]:

- A lack of direction;
- A lack of planning;
- A lack of adequate project sequencing.

The authors add that their knowledge of particular tools and techniques exists, but the overall strategy and perspective must match the lean approach.

3.4 Evaluation and feasibility of the Lean tools

After introducing 18 lean tools in the previous subchapter, the author decided to use only some specific tools for the actual state analysis in chapter 4. In the first subchapter of the actual state analysis, the author aims to identify the production bottlenecks. Based on that goal, the author compared all the lean tools with each other. The criteria for comparison were:

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[1] Claimed by Mora in 1999, and by Sohal & Egglestone in 1994.

- Ease of use
- Cost of usage
- Time efficiency
- Applicability
- Measurability
- Comprehensibility

Table 3.4 displays the developed evaluation matrix. The rewarded points are between one and five, where one is the lowest and five the highest possible score. The marks depend on the suitability of the proposed lean tool and are based on the author's research and his previous experience with the tools.

Table 3.4 Lean Tool Comparison for the Bottleneck Analysis

Bottleneck Analysis							
The rewarded points are between one and five, where one is the lowest and five the highest possible score depending on the suitability of the proposed lean tool to the existing production processes in Defendec.							
	Parameter						
Method	Ease of Use	Cost of Usage	Time Efficiency	Applica-bility	Measura-bility	Comprehensi-bility	Points
7 Wastes	4	5	2	2	2	4	19
Key Performance Indicators	3	3	4	3	5	3	21
Gemba	4	2	3	4	3	4	20
Jidoka	1	1	1	1	2	4	10
Andon	3	3	2	1	4	5	18
Poka Yoke	4	4	4	1	2	4	19
5S	3	4	3	2	2	3	17
Kaizen	3	4	2	1	2	4	16
Time and Motion Study	3	3	3	2	4	3	18
SMED	1	2	2	1	4	3	13
Bottleneck Analysis	4	3	4	5	5	5	26
Heijunka	2	2	2	1	5	3	15
Root Cause Analysis	4	4	4	2	2	3	19
Failure Mode and Effect Analysis	4	4	3	2	2	4	19
Standardized Work	3	3	3	1	3	3	16
Value Stream Mapping	3	2	3	5	5	4	22
Kanban	3	2	3	1	3	3	15
PDCA and DMAIC	5	2	4	2	2	3	18

Based on the cumulated values in Table 3.4, the most suitable tools for the production flow and bottleneck analysis are:

- Value stream mapping;
- Bottleneck analysis;
- Key performance indicators;
- Gemba.

When comparing these four tools, companies can use the Gemba walk method for minor problems, where the actual location is observable all at once. Gemba is mostly applied after specific issues have been detected that need further investigation. Key Performance Indicators, by comparison, are an objective method for evaluating production, process, or task efficiency. However, key performance indicators by themselves lack to show the interdependencies between the different processes. They should instead be used together with other tools for measurement and evaluation. For example, the author will exploit the KPIs employee and workstation utilization in chapter 4.1 to find the bottlenecks.

For an overview, the most suitable approaches are the value stream mapping approach or the bottleneck analysis. Both should include KPIs for better comparison and involve being at the actual place or going to the Gemba. The benefits of the value stream method are the detailed reproduction of the facility and the visual appearance. This standardized form of presentation – in Figure 3.5, a current state analysis was shown - makes it easy to process the collected data.

The bottleneck analysis in comparison is simplistic and can be performed on any level of detail according to given requirements. Moreover, the tool focuses on the integral part, which convinced the author to use this method to identify the most severe production problems at Defendec. The analysis is also partly based on KPIs; among them are:

- Processing times;
- Employee utilization;
- Workstation utilization.

After the bottlenecks – warehouse and packaging area - are detected in chapter 4.1, the in-detail analysis needs additional lean tools to achieve the best possible result when analyzing and solving the problem. Therefore, the author decided to create one more evaluation matrix. Even though the parameters are the same, the classification is different since it is based on another goal. Table 3.5 shows the results of the evaluation matrix for the in-depth analysis of the detected bottlenecks in chapters 4.2 and 4.3.

Table 3.5 Lean Tool Comparison for the In-detail Analysis of the Detected Bottlenecks

In-detail Analysis of the Detected Bottlenecks

The rewarded points are between one and five, where one is the lowest and five the highest possible score depending on the suitability of the proposed lean tool for the detected bottlenecks.

Method	Parameter						Points
	Ease of Use	Cost of Usage	Time Efficiency	Applicability	Measurability	Comprehensibility	
7 Wastes	5	5	4	5	3	4	26
Key Performance Indicators	3	3	3	2	5	3	19
Gemba	4	2	3	4	2	3	18
Jidoka	1	1	1	2	3	4	12
Andon	2	3	2	3	3	5	18
Poka Yoke	3	4	3	3	1	4	18
5S	3	4	3	4	3	3	20
Kaizen	3	4	3	3	2	4	19
Time and Motion Study	4	3	4	5	5	3	24
SMED	1	2	2	1	3	3	12
Bottleneck Analysis	3	3	2	1	3	5	17
Heijunka	2	2	1	1	4	3	13
Root Cause Analysis	4	4	3	3	1	3	18
Failure Mode and Effect Analysis	3	3	2	4	2	4	18
Standardized Work	3	3	3	3	3	3	18
Value Stream Mapping	3	2	2	1	3	4	15
Kanban	3	2	2	1	3	3	14
PDCA and DMAIC	5	2	3	3	2	3	18

After conducting the evaluation matrix, the author decided to utilize the three lean tools with the best score: seven wastes, time and motion studies, and 5S. Those are the most suitable tools because the bottlenecks – warehouse and packaging area – must be improved in their operating methods and design. The three tools complement each other and are self-explanatory. The seven wastes give a general overview of the different types of waste, while the 5S method encourages an overall clear, transparent, and standardized workplace with the best practice in place. A time and motion study is especially suitable for the new workstation design of the packaging area in chapter 4.3 because workflows and the overall workstation design will be changed. In this case, the author refers primarily to Figure 3.3, which describes the parameters on which the worker's efficiency is based.

Tools like Jidoka, SMED, and Andon are less suitable because currently, the production is performed manually. Only some computers are integrated into the system, but those are not associated with the bottlenecks. Heijunka or the production flow leveling is less suitable too. As explained in chapter 2.2, the devices are produced in batches, and the number of employees is not sufficient to perform all tasks simultaneously. Batches and workstations are more likely to wait for an idle employee than vice versa. The bottleneck analysis in chapter 4.1 proves this claim.

General tools like Kaizen, five why, and PDCA cycles are partly mentioned and set the framework for this thesis. However, the in-depth analysis, as already mentioned earlier, is done by more assaying and informative tools.

4. ACTUAL STATE ANALYSIS

4.1 Production Flow and Bottleneck Analysis

The production flow analysis is conducted using the simulation software Arena and aims to find bottlenecks. The chosen software is used for modeling and simulating business processes. It is specially designed to visualize complex supply chains, productions, services, and other process chains [53].

As already mentioned, the author used Arena for the analysis. However, a decision was made between different modeling and simulation software: Visual Components [54], Arena Simulation [55], and Tecnomatrix Plant Simulator [56]. The author decided based on the ease of use, the user interface, previous experience with the programs, comprehensibility, and the availability of the program. Table 4.1 shows the result of the comparison.

Table 4.1 Simulation Tools Comparison for the Bottleneck Analysis

Simulation Tools Comparison						
The rewarded points are between one and three, where one is the lowest and three the highest possible score depending on the simulation software's performance for each parameter.						
	Parameter					
Simulation Software	Ease of Use	User Interface	Previous Experience	Comprehen-sibility	Availability	Points
Visual Components	1	3	2	2	2	10
Arena Simulation	3	3	2	2	3	✓ 13
Tecnomatrix	3	2	2	3	2	12

In the author's opinion, Arena is the most suitable software because process chains can be rebuilt quickly. The user interface is self-explanatory, and a well-made KPI reporting system is directly included. The two other options – Tecnomatrix and Visual Components – are more suitable for fully functional digital twins, including robots, which are non-existing at Defendec.

The present analysis is based on the detector manufacturing process because the device has the highest production volume. The bridge and siren process chains are similar and can be compared to the detector's one. A separate assessment is not necessary. The detector manufacturing includes 12 steps listed with their average processing time in Table 4.2 below. The processing times have been multiplied with a factor due to confidentiality reasons. Figure 4.1 visualizes the sequence and dependencies between the processes.

Table 4.2 Manufacturing Times for the Detector Device

	Ø time	
Manufacturing process	**in mm:ss**	**in seconds**
Enclosure A preparation	0:39	39
Enclosure A assembly	5:54	354
Enclosure B preparation	0:39	39
Enclosure B assembly	6:20	380
Enclosure B stacking	5:47	347
PCB Testing and programming	10:43	643
PCB Testing and programming 2	3:54	234
Camera module focusing	4:42	282
ERP registration	8:36	516
Final test and assembly	4:42	282
Parcel folding	2:15	135
Packing	3:20	200
Sum	**57:31**	**3.451**

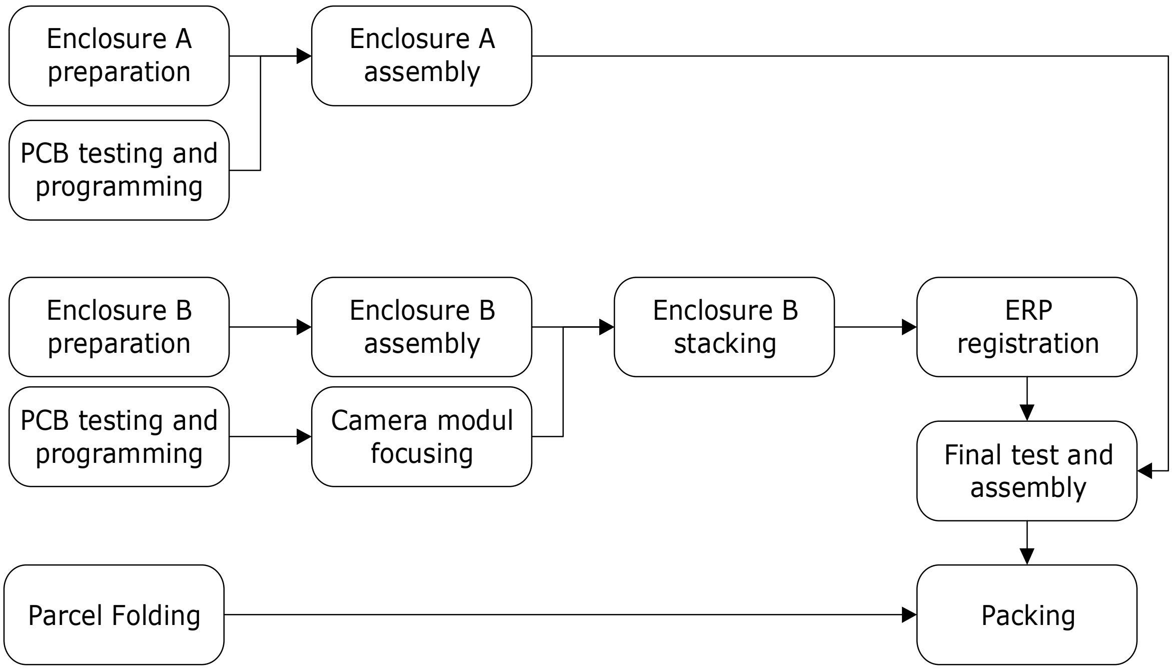

Figure 4.1 Manufacturing Sequence for the Detector Device [57]

The production process begins with five tasks, which can be performed simultaneously. Currently, this is only utilized partially because the number of employees is limited, as written in chapter 2.2. It all starts with the preparation of the back and front enclosures. This step includes clipping and gluing. A minor part of the enclosure must be removed in both cases, which would otherwise interfere space-wise with the later added components. A sub-contractor molds the enclosures. Therefore, the molding tool would need to be redesigned for a design change. The gluing is done to strengthen the main inserts for better adhesion between the plastic enclosure and the inserts. After the preparation, enclosure B can already be assembled, adding and fixing all components within the detector.

Another task that can be done in the beginning is to program and test the electronic modules. The four modules are:

- PIR module
- Radio module
- Camera module
- IR Flash module

All modules except for the camera module are ready to be stacked into the enclosures after the testing. The camera module undergoes one more process, where the day and night cameras are focused. In the process enclosure B stacking and enclosure assembly A, the modules are screwed into the device with all the other components. When the back and front enclosures are ready, they are created in the ERP system to ensure they have a serial number, ID, and the correct customer-specific security certificate. During this administrative task, the worker takes a test photo to ensure the device works properly and connects to an existing bridge communication system. If the test is positive, the final assembly occurs, where the front and back enclosures are sealed together. Next up, the detectors are transported to the packaging area by using a trolley. The devices are placed into the pre-folded parcels, which can be folded at any time during the whole manufacturing process. In addition, accessories are added to the packages. Sometimes orders include additional accessories, which are then packed into separate boxes.

The Arena model, depicted in Appendix 1: Arena Simulation Model, is based on the previously explained detector workflow. The general setup of the whole system is based on a runtime of 8 hours and the manufacturing of 15 devices by two employees – a production specialist and a production worker. They are assigned different tasks, depending on their complexity. The model is further restricted by the fact that each job must be performed at a specific workplace. For example, the parcel folding and the packaging are both done at the packaging table and cannot be performed simultaneously. The same thing applies to all other tasks regarding the available workforce. The other previously mentioned workers in chapter 2.2 are allocated to the other two products.

The five arrow boxes, in the beginning, are necessary to create the input or, in this specific case, the essential components. The author defined the arrival as a single delivery of 15 pieces directly at the beginning of the simulation process. Afterwards, the mentioned processes from Table 4.2 must be passed to generate a packed detector that can be shipped. The processing times are based on a triangular distribution. Figure 4.2 explains the triangular distribution graphically for a better understanding.

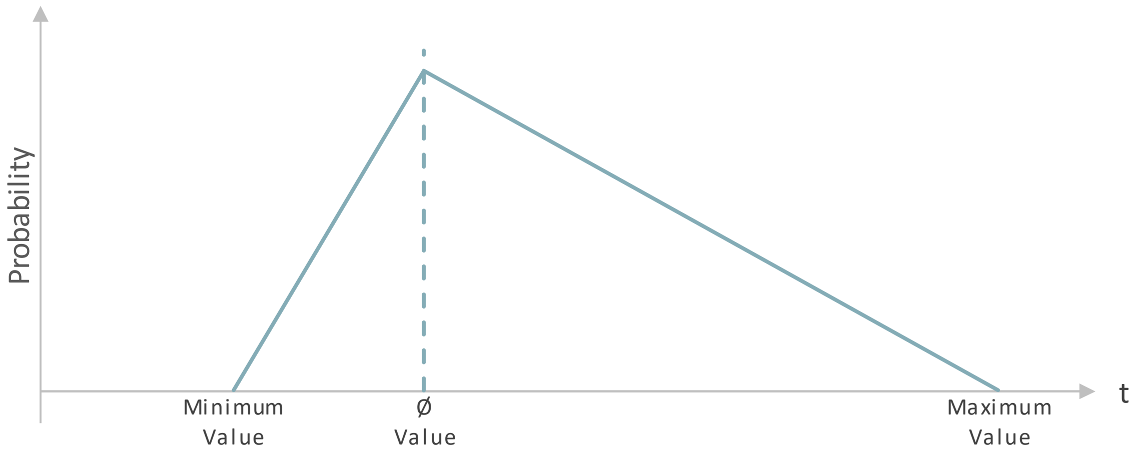

Figure 4.2 Triangular Distribution

The most likely value is based on the average timing for each process from Table 4.2. The minimum and maximum values vary depending on physical observations. For instance, the PCB programming and testing fails one in a while, which leads to a long delay. In general, the processing times are varying heavily. On the other side, parcel folding is a simple task. If the carton is not damaged somehow, it is almost impossible to do it incorrectly, resulting in a much narrower triangular distribution.

The additional four boxes named Match 1-4 connect the separate process flows before assembling in the next step. The four match boxes do not add any processing times to the simulation but measure the waiting time if one of the two components is missing. Lastly, the arrow box at the end is defined as output and reports additional KPIs.

The simulation results in the manufacturing of 15 detectors within 8 hours when utilizing one production specialist and one production worker. Figure 4.3 displays the utilization of the employees as well as from the workstations.

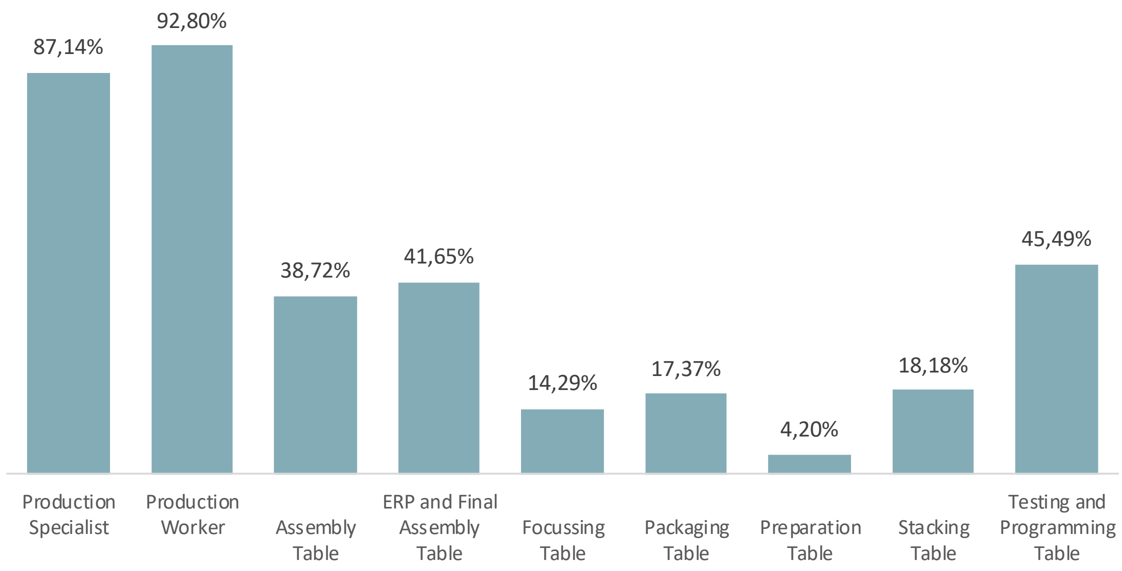

Figure 4.3 Employee and Workstation Utilization according to the Arena simulation model

The employee utilization is by far the highest. Hence, Defendec is outsourcing some parts of the production and has several production workers at hand. The workstation utilizations are lower because the tasks cannot be performed simultaneously when only two employees are available. However, additional employees use the workstations and increase the utilization to manufacture the other two devices.

The PCB programming table and the final assembly and ERP table reach the highest values. This is one of the bottlenecks because they rely on a channel-specific communication network and cannot be performed simultaneously. The development department of Defendec is already working on a solution to fix the problem.

A somewhat hidden bottleneck is the packaging table. The utilization is low based on the number of produced detectors. However, all bridges and sirens are packed at the same workplace. All parcels are prepared there as well, which directly increases the overall utilization. Mainly since the siren parcels include a fixing system that is based on the bridge’s one, some manual cutting operations must be performed to make sure the siren fits into the parcel. In contrast, the bridge and siren assembly have their workplace, which results in a fixed utilization of the assembly table.

Lastly, when collecting the simulation data, it became apparent that searching for tools and components in the warehouse was a common issue, resulting in an overall waste and non-value-added time according to the explained lean principles in chapter 3.1. The stored components are only partly marked and stored at familiar places for the experienced employees. Neither a specific classification system exists nor fixed positions for each component.

Out of the three bottlenecks, the author will analyze the warehouse and packaging under consideration of lean principles. The current state analysis for the warehouse can be found in subchapter 4.2, while subchapter 4.3 presents the packaging area. The first bottleneck regarding the programming and testing of the electronic modules is currently under investigation by the development department. It cannot be solved directly in the production because it includes coding and other necessary competencies covered within their department.

Figure 4.4 shows how the two bottlenecks, which will be solved during this paper, affect the process chain. The processes in blue are impacted by the warehouse, while the orange ones are performed at the packaging area. Except for ERP registration, all operations are marked in blue because they require components stored in the warehouse. Therefore, almost all processes will be slightly improved when optimizing the storage system.

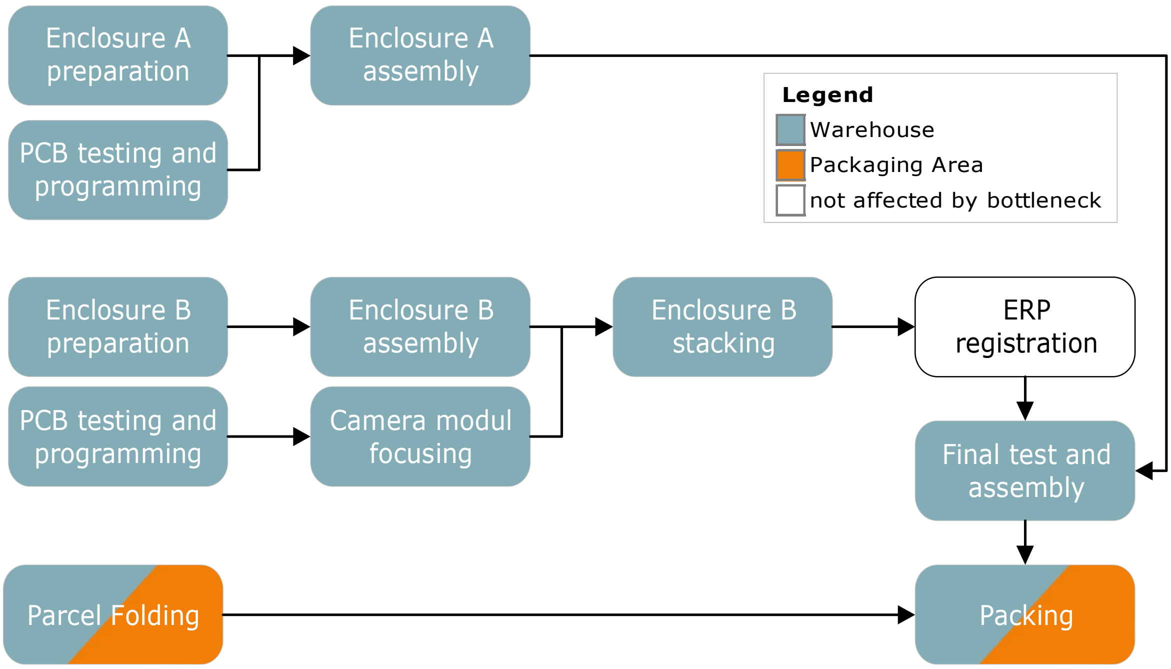

Figure 4.4 The Negative Impact of the Bottlenecks on the Manufacturing Sequence

4.2 As-Is Analysis of the Warehouse

One of the three detected bottlenecks identified during the analysis in chapter 4.1 is the warehouse. Therefore, this chapter will describe and analyze the current situation with its problems. Chapter 5.1 presents an optimized concept based on the achieved results from this chapter.

The warehouse is depicted in Figure 4.5 for a better understanding and to get a visual impression. Figure 2.6 stated previously showed the location of the warehouse within the premises. The first three pictures are showing the warehouse from different angles or rather corners of the room. The last picture in the lower right gives a front view of two shelves, where accessories for the packaging area are stored, to get a better impression of the current situation.

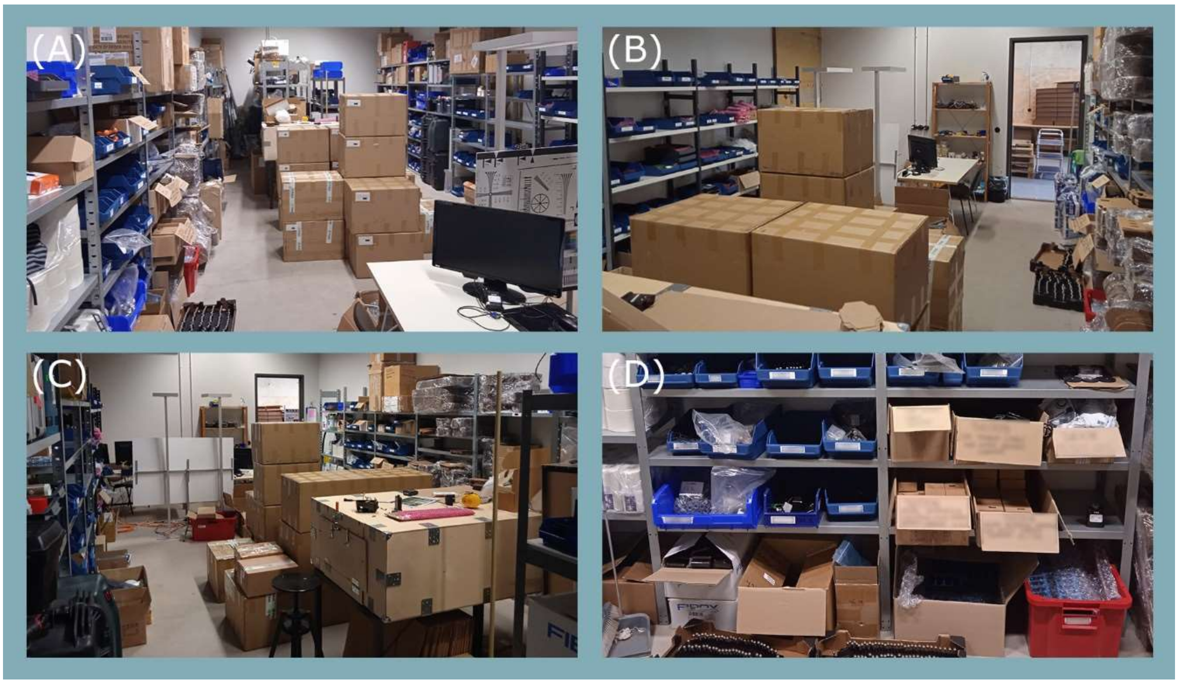

Figure 4.5 The Warehouse of Defendec – (A) General view from the entrance door (B and C) General view from the back corners of the room (D) Shelve close-up view

In total, the room has 26 shelves in four separate rows. Next to the door is one workstation, where one worker can test and focus camera lenses. The task is done inside the warehouse because one process step requires darkness. This can easily be achieved in a room with no windows. The boxes in the middle of the room are new components that just arrived and are not yet registered into the ERP system. If this is done, they can be unpacked and stored correctly. The wooden box, which can be seen best on the third picture in the lower-left corner, is a soundproof box for testing the siren’s sound.

The warehouse is not only used by the production but by the other departments as well. Therefore, out of the 26 shelves, 12 are used by the production department. They are located nearest to the exit because they have the highest warehouse throughput. Table 4.3 states how the shelves can be further divided into separate categories.

Table 4.3 Storage Categories in the Warehouse

Storage Category	Number of Shelves
Production Components	8
Parcel Packaging Material	2
Accessories	2
Non-production related storage	14
Total	**26**

Parcel packaging material describes the carton used for the boxes and the interior parts of them. The accessories are added to the boxes in the packaging area but are not used beforehand. The eight shelves with production components include everything until the devices are assembled and ready to be packed. The parts are currently stored at any place, which might change over time if not enough space is available. A particular sorting system based on the different devices does not exist. Keeping an overview can be challenging because there are 158 production parts listed in the ERP system. Table 4.4 displays an approximation for the most essential and prominent groups.

Table 4.4 Component Categories in the Warehouse

Component Category	Number of Parts
Detector	35
Bridge	25
Siren	30
Sold Items (Accessories)	60

Overall, the warehouse lacks a clear concept for finding the right components promptly. From a theoretical viewpoint, the total operation time can be reduced when following the worker's efficiency model from D. R. Kiran, described in chapter 3.2. The waste of time is based on case B2 "ineffective method of operation" (see Figure 3.3 in chapter 3.2). The time wasted adversely affects all other processes mentioned during the bottleneck analysis in chapter 4.1 because all of them include getting the necessary components out of the warehouse. Every second spend in the warehouse searching for parts can be reduced. From a seven wastes method viewpoint, this problem would classify as a waste of motion.

As already mentioned, the space allocation is flexibly designed, and the shelves are not marked in any way. The product codes are written directly on the boxes and storage containers. A particular order is not supported by the current system and cannot be achieved. Storage space is lost because the layer height cannot be changed according to the storage container size.

4.3 As-Is Analysis of the Packaging Area

After conducting the bottleneck analysis in chapter 4.1, it became clear that the packaging area is one of the most critical problems to be solved. For a better understanding, Figure 4.6 shows the packaging area.

Figure 4.6 Packaging Area at Defendec Before Optimization

The final products – detectors, bridges, and sirens – are stored on the right, most likely on the trays. If the production needs empty trays again, they are relocated onto the table or the upper layers of the shelf. The boxes on the tables are the result of the parcel folding process mentioned earlier in chapter 4.1. The bigger ones are for the bridges, the smaller ones are for the detectors, and the ones in the corner below the left table are for the sirens. Figure 4.7 exhibits the different boxes with their packaging interior, devices, and accessories.

Figure 4.7 The Different Packaging Boxes

Currently, the employee places the sirens into the bridge boxes, which forces the employee to cut out one part of the carton because the siren beacon needs more space. The accessories, shown in Figure 4.7, are transported from the warehouse to the packaging table whenever required. However, they do not have a predefined position at the workplace. The number of accessories is counted before bringing it to the packaging area to ensure each box is packed correctly without missing parts. Packing the accessories directly when folding the boxes is impossible because the supplements are based on the customer's order and might vary.
Each parcel can be closed after adding all the accessories and the product. Then an adhesive label is added to seal the packaging. The label includes a short description of the product type and has a unique device-based code on it. Adding this unique code on the parcel forces the employee to check and compare the code with the device itself before closing the parcel. This step cannot be removed because the unique code is connected to the security certificate and other specific settings.

In the end, the employee places the parcels into larger boxes for shipping purposes. In total, they can carry up to twelve detectors, six bridges/sirens, or a mixture of both.[1] The empty shipping boxes can be seen in Figure 4.6 under the left table. The shipping boxes are then weighted and carried near to the entrance. The electronic scale can be seen on the euro pallets in Figure 4.6.

Based on the theory in chapter 3.2, the author decided to use Gemba to analyze the packaging area. Table 4.5 gives an overview of the detected problems. The author will explain them in more detail by utilizing several lean tools from chapter 3.2.

Table 4.5 Detected Problems at the Packaging Area

Nr	Problem Description
1	The devices are unloaded from the trays, because they are needed somewhere else.
2	The table heights are non-ergonomically for an upright working position.
3	The scale is located on the floor, which is non-ergonomically.
4	There is only a visual inspection whether all accessories have been added into the boxes.
5	The Siren cartboard box has to be specially cut out to have enough space for the siren beacon.
6	There is no fixed position for all the accessories or anything else, nothing is standardized.
7	The door treshholds limit or rather slow down the trays in their movement within the premises.
8	Several components are stored below the tables without any specific order.
9	The adhesive labels are stored in a small blue box and their handling process is suboptimal.
10	The packaging tape, cutter knifes etc. could be stored closer to the packaging area.

The first problem describes the already mentioned practice of storing devices on the tables until packaging if the trays are needed otherwise. This is waste in the form of transportation and motion. The devices are carried just a few centimeters to the side, not adding any value to the products. Since the task is performed by an employee and is not automated, it also includes unnecessary motion. Furthermore, every movement increases the likelihood of occurring defects in the electronic parts. Moreover, the devices are placed on the trays according to a specific order. The sequence is based on the customer and their unique security certificate. An incorrect sequential order might occur when relocating the devices one by one. It would be detected later when adding the adhesive labels but would increase packaging times.

[1] The bridge and siren boxes are twice the size of the detector ones.

The second problem is influencing the worker's efficiency, according to D. R. Kiran[1]. Figure 3.3 gave a graphical overview of the factors. For this problem, case C5 - bad working conditions - applies. All packaging tasks are performed while standing. However, the two tables on the right in Figure 4.6 are classical workplaces with a height of only 73 cm, compared to the table on the left with 91 cm. In theory, the left table is for works carried out standing, while the other two are for tasks, which require sitting down. Therefore, ergonomically the workplace is not adequately designed.

The next problem is based on the same worker's efficiency factor. In the past, the electronic scale was located on the ground. By now, as shown in Figure 4.6, the electronic scale is placed onto several euro pallets, resulting in a better workstation design and less heavy lifting for the employees. The improvement was already recently implemented due to its simplicity.

Another problem is that employees make mistakes when inserting all the accessories into the boxes. Currently, there is only a visual inspection by the employee itself. Wrongly packed parcels might only be detected if all accessories were counted beforehand and taken out of the warehouse separately to fulfill the order. In practice, failures occur when pre-counting the parts. If accessories are missing, the packages must be opened until the error can be detected and corrected. Based on the proposed solution in chapter 5.2, the process includes an unnecessary motion for counting the accessories beforehand. The wrongly packed boxes are regarded as defects and are counted as waste as well. Overall, the work content is poorly designed and results in an uneconomic process[2] , according to D. R. Kiran.

The fifth problem can be categorized as A4 of the worker's efficiency factors: Design demands removal of excess material. The current siren solution utilizes the bridge cardboard box. Figure 4.8 shows the siren box with all cutting lines in orange.

[1] Further explanations can be found in the theory chapter 3.2.

[2] Case A1 in Figure 3.3

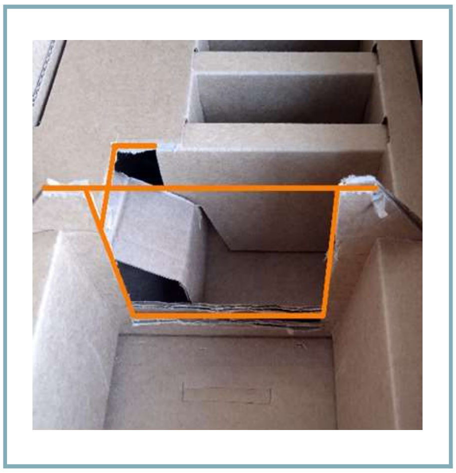

Figure 4.8 Siren Box Before Optimization with Manually Cut-out Areas

Overall, excess material must be removed, leading to a motion waste by the employee. Furthermore, the risk of injuries increases when using cutter knives.

When the employee is currently performing the packaging task, he picks up all accessories from the warehouse and places them randomly on the table or nearby, wherever he finds space. According to case A2 of the time and motion study by D. R. Kiran, the lack of standardization adds ineffective times. The placement is most likely not ergonomically optimized but instead based on a spontaneous decision. Case B4 - bad layout causing wasted movements - might also occur if the employee is not trained in lean methods or time studies. This problem can also be detected when following the 5S procedure while performing the Gemba. The second step stands for “Set in order” and describes a place for everything. Further information regarding the 5S method can be found in chapter 3.2.

The seventh problem is not solely connected to the packaging but has an overall negative influence on production. The production facility layout was presented earlier in Figure 2.6. As shown in the figure, doors separate the warehouse, packaging area, and the office with the main entrance. The problem is that both doors have doorsteps, which can be overcome by slightly lifting the transportation trays. However, this step takes time and is cumbersome.

The next problem – components stored randomly below the table – is similar to the sixth one. It includes a lack of standardization and causes wasted movements, which are unergonomic because employees must bend over. It also interferes with the 5S concept of having for everything a predefined space.

The ninth problem deals with one of the last steps in production. The boxes are being sealed after they are equipped and closed. As already mentioned, the unique code on the adhesive label is compared with the device placed into the box. Therefore, the employee must take the label role into his hand twice – one when comparing and once when pulling off the label from the protective film. Based on the solution presented in chapter 5.2, the task can be performed quicker and more efficiently. It involves less movement, solves the problem of the protective film trash, and results in a faster and more economically designed process.

The last problem is explicitly addressing the smaller packaging materials like knives and tape. Currently, they are stored in the warehouse just a few meters far away. Figure 4.9 shows the shelve and its content.

Figure 4.9 Packaging Material Shelve in the Warehouse Before Optimization

The upper two levels, which include essential packaging tools, could be stored directly in the packaging area, reducing the employee's waste of transportation and motion.

After listing all the detected problems in Table 4.5 and explaining them in detail with the help of the fundamental lean concepts – seven wastes, 5S, and time and motion study – the solutions for each problem will be presented in chapter 5.2

5. CONCEPT DEVELOPMENT

5.1 The Concept for the Warehouse

For a more transparent, time-efficient, and space-efficient warehouse, the author proposes to implement three main improvements:

- Standardize boxes and the shelve layer spacing according to the box sizes;
- Implement label holders at the shelves and the standardized boxes;
- Implement a color-coding system to differentiate product-specific components.

As it was shown previously in Figure 4.5, the current components are stored primarily in cartons of different sizes. However, this leads to unused space in each shelve because the layer spacing is based on the tallest carton. It would be beneficial when the components are directly unpacked after registering them in the ERP system and placing them into standardized boxes. Currently, this task is performed when the employee needs them for the upcoming assembly process. In some cases, the employee takes the cartons without refilling them into the boxes. If there would be standardized workplaces with predefined component areas, this would most likely not work out anymore. Figure 5.1 displays the standardized containers with measures.

High Large Box	Low Small/Medium/Large Box	Small Screw Box

23,5 x 39,5 x 15 cm	23,5 x 39,5 x 9,5 cm 17,5 x 39,5 x 9,5 cm 09,0 x 39,5 x 9,5 cm	10,5 x 16,5 x 7,5 cm

Figure 5.1 Standardized Boxes at Defendec

In the next step, the forefront of each standardized box should be marked with self-adhesive label holders to specify what component is stored inside. Figure 5.2 shows an adhesive label holder. The label can be exchanged easily at any time without residues. Therefore, this should be preferred over gluing the labels directly onto the box as it is currently done.

Figure 5.2 Self-adhesive Label Holder for Standardized Boxes [58]

At the same time, the warehouse needs to be equipped with label holders to promote a fixed layout reducing the searching time for employees. In the warehouse, magnetic label holders, as shown in Figure 5.3, should be used because changes to the system will occasionally occur due to new components, accessories, or changing inventory numbers.

Figure 5.3 Magnetic Label Holder for Warehouse Shelves [59]

Lastly, the labels must have the same structure, including a color-coding. The author proposes seven different background colors for the following categories:

- Detector components;
- Bridge components;
- Siren components;
- Shared components;
- Accessories;
- Defect/discarded parts;
- All other production-related items.

The author proposes to print the article name, the article number, and the barcode onto the labels. A possible label design for the tags can be seen in the graphical material on page 74. Two different drawings are required because the magnetic and the self-adhesive label do not have the same size. Currently, the production employees do not actively use the barcode, but this will most likely change when the production numbers increase. If the business keeps growing, it would be possible to scan the barcode at the standardized box and a shelve layer-specific barcode to implement a digital storage system within the ERP. Currently, only 12 shelves are used, and a color-coding storage system is sufficient. A short ERP search query might even take longer than just detecting the parts by the color system.

5.2 The Concept for the Packaging Area

After identifying ten problems regarding the packaging area in chapter 4.3, the author proposes solutions to each of them in this chapter. Table 5.1 lists the issues again for better readability. In chapter 4.3, detailed explanations for each problem can be found.

Table 5.1 Detected Problems at the Packaging Area

Nr	Problem Description
1	The devices are unloaded from the trays, because they are needed somewhere else.
2	The table heights are non-ergonomically for an upright working position.
3	The scale is located on the floor, which is non-ergonomically.
4	There is only a visual inspection whether all accessories have been added into the boxes.
5	The Siren cartboard box has to be specially cut out to have enough space for the siren beacon.
6	There is no fixed position for all the accessories or anything else, nothing is standardized.
7	The door treshholds limit or rather slow down the trays in their movement within the premises.
8	Several components are stored below the tables without any specific order.
9	The adhesive labels are stored in a small blue box and their handling process is suboptimal.
10	The packaging tape, cutter knifes etc. could be stored closer to the packaging area.

First, the author proposes to remove the two smaller tables with the lower table height. Instead, a table of the same size as the one on the left in Figure 4.6 should be added. The table height should be around 91 cm because all tasks there are performed while standing. The same principle goes for the scale, which should be placed at the height of approximately 60 cm. This improvement was already implemented by the author when the picture for Figure 4.6 was taken. Implementing these two proposals will solve problems two and three from Table 5.1. In total, space will be saved as well, which reduces the storage capacity on the tables. However, problem one clearly states that unloading the trays on the table does not add any value to the product. The production department should buy additional trays instead to eliminate the waste of motion and transport. The area has more space for the trays as well, after removing one of the three tables.

Problem four can be solved by implementing a scale to weigh packed device boxes. The lightest accessory part weighs 0,011 kg, as shown in Table 5.2.

Table 5.2 Weight of Each Device and Component for Shipment

Device / Component	Weight in kg
Detector	0,434
Bridge	0,657
Siren	0,941
Carton Detector	0,121
Carton Bridge	0,282
Carton Siren	0,271
Antenna	0,061
Battery	0,200
Mounting Screw	0,016
Mounting Bracket	0,095
Leaflet	0,011

A classical small-scale kitchen scale that measures in grams and goes up to 2,5 kg is sufficient to perform this task. For instance, a packed detector box weighs 0,866 kg when including a battery, mounting bracket, and mounting screw. The antenna and leaflet are exclusively packed into bridge and siren boxes.

The author recommends a digital scale because they are more accurate than analog ones, and their readability is user-friendly. However, digital ones usually shut down automatically after a while, leading to an additional process task and a waste of motion. The other option is to find a digital scale, which does not include an automatic cut-out. When implementing a measurement system for each box, the accessories would no longer be counted beforehand, saving a lot of time. Furthermore, any packaging mistake is detected directly and not when the complete shipping box of six to twelve devices is weighted. In the past, the boxes had to be re-opened until the faulty box or boxes were found.

The solution for number five - the non-existing siren cardboard box - is already in development. Until then, the bridge boxes must be cut to fit the siren devices inside. Figure 5.4 shows the most recent proposal from the cardboard supplier.

Current Siren Box
with Cutting

Siren Box Prototype
without Cutting

Figure 5.4 Siren Box Prototype from the Cardboard Supplier

The prototype is still under development and cannot be used because the material's stability is not sufficient. In addition, Defendec is investigating other packaging options. Specifically, pulp packaging material because it is getting cheaper and is environmentally friendly. The molded pulp packaging is made from recycled paper and other fibrous materials like sugarcane, bamboo, or wheat straws [60]. The material is formed to shape and can replicate complex three-dimensional shapes [61]. One very well-known example is an egg carton. Figure 5.5 shows a general example.

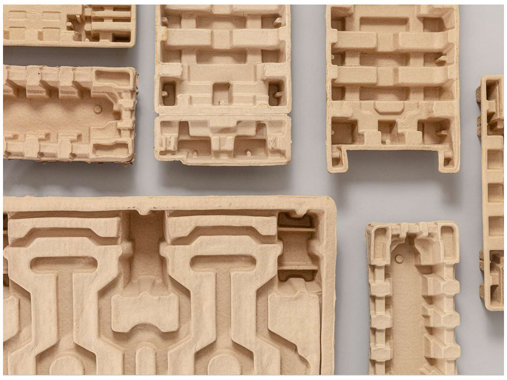

Figure 5.5 Pulp Packaging Material [61]

After implementation, the packaging process for each siren will be on average 65 seconds faster due to eliminating the cutting part.

The landlord, who rents out the premises to Defendec, can solve the seventh problem concerning the door thresholds. Within the next two months, the production will be relocated within the building to the ground floor. There, the thresholds also exist but will be removed before moving in. An uninterrupted movement of trays will be possible, leading to faster transportation and less motion, including lifting trays by the employee. The main benefit will be that the shipping boxes can be placed ergonomically from the scale seen in Figure 4.6 directly onto the trays. Afterwards, the shipping boxes can be rolled out of the production to the main entrance, where the freight forwarder picks them up. However, removing the door thresholds does not only reduces the processing times of the packaging area. It also affects all transports between the warehouse and the production, which are performed using the trays.

Problems six and eight are both connected to standardizing and tidying the workspace. The author proposes to keep the empty boxes on the table, where they can be easily reached when starting to package the devices. However, the accessories – batteries, mounting screws, mounting brackets, and antennas - should be stored slightly below the table. Figure 5.6 shows an example.

Figure 5.6 Exemplary Workstation with component storage marked in orange below the table [62]

This design would allow the employee to pack the devices and accessories into the box efficiently. Combined with the weight measurement, it would be time-efficient and less error-prone. Furthermore, it is more ergonomically than before, where the accessories were stored randomly at all different places. Long-term negative impacts like back-problems etc. will be minimized by creating a standardized workplace. Generally, the accessories are delivered in identical box sizes every time, making it possible to avoid any component refilling before they can be placed slightly below the table.

The solution presented in Figure 5.7 can solve the ninth problem.

Figure 5.7 Label Dispenser and workplace design [63]

A label dispenser can be seen on the left, which will be fixed to the packaging table. The worker must pull at the paper strip to separate the label and the label. The process can be performed with one hand and is much faster. On the right, the process is illustrated for a better understanding. The holding device will be exchanged, but the rest could be implemented as shown in the picture. If the label dispenser is fixed at the table's edge, a trash bin can be placed directly below for the paper disposal. Beforehand the removal was done manually, while the proposed solution gets rid of this additional process.

The last problem is very general and is already partially solved after implementing the previous proposal. The adhesive tape can be stored below the left table, and smaller items like the cutter knives and the tape dispenser can be placed into a standardized box next to the scale.

6. IMPLEMENTATION PLAN

Implementing the proposed changes will be done when relocating the production in June or July to the ground floor of the same building. The warehouse will be brought downstairs as well. The overall layout will change to a clearer and streamlined production. Implementing the changes before the relocation would lead to a wasteful and time-consuming twofold implementation, which is not beneficial to the company.

The first step regarding the warehouse bottleneck is to store all components in standardized components when the supplier delivers them. This allows changing the number of shelve layers according to the box's height. The second step is to equip all storage containers with label holders. The label with its color-coding explained in chapter 5.1 helps to increase efficiency when searching for parts. In the third step, label holders are added to the shelves to implement a fixed position for each component.

At the same time, the packaging area optimization proposals can be executed. Here, the first step will be to rearrange the packaging area, including implementing the new table. Afterwards, the operating procedure will be changed, e.g., setting up the label dispenser. All ten improvements for steps one and two can be found in chapter 5.2. Step three is training the employees to make sure that they are following the standardized processes.

After the implementation, it is essential to act according to the lean principle of continuous improvement. New production layouts might create unanticipated problems that need to be solved. In addition to that, new devices are being under development, which will include other components and accessories. A completely new warehouse system or packaging area will not be necessary, but changes must be made to ensure processes are performed ergonomically and efficiently in the future.

7. FINANCIAL FEASIBILITY ANALYSIS

For evaluating the suggested improvements, the author performs a return-on-investment analysis within this chapter. The cost of implementation will be gathered and set off against the savings. The calculations are based on Euro per 1000 units. The number of produced devices per month or year cannot be published due to confidentiality. Therefore, the values are not based on time but on the number of produced goods. Consequently, all variable values are based on 1000 production units, while fixed costs for implementation are not affected. Table 7.1 lists all cost factors necessary to implement the changes proposed in chapters 5.1 and 5.2.

Table 7.1 Cost Factors for the Break-Even Analysis

	Bottleneck	Description	Total Cost	Type of Cost
Cost	Warehouse	100 standardized boxes	640,00 €	One time payment
Cost	Warehouse	200 self-adhesive label holders	85,00 €	One time payment
Cost	Warehouse	200 magentic label holders	67,00 €	One time payment
Cost	Warehouse	Label printing incl. Paper	10,00 €	One time payment
Cost	Warehouse	Labor for implementation	81,60 €	One time payment
Cost	Packaging Area	1 new table	410,00 €	One time payment
Cost	Packaging Area	3 additional trays	510,00 €	One time payment
Cost	Packaging Area	1 (kitchen) scale	20,00 €	One time payment
Cost	Packaging Area	Removing the door thresholds (done by landlord)	0,00 €	One time payment
Cost	Packaging Area	Labor for implementation	108,80 €	One time payment
		Fix costs (one time payment)	**1.932,40 €**	
Cost	Packaging Area	Modifying the packaging material	75,60 €	per 1.000 units
		Variable costs (per 1.000 units)	**75,60 €**	
Saving	Warehouse	Time saved by faster component pick-ups	453,33 €	per 1.000 units
Saving	Packaging Area	Benefits due to more ergonomical working conditions (back problems, sick days)	81,60 €	per 1.000 units
Saving	Packaging Area	7% Time saving at the packaging table due to optimization	57,23 €	per 1.000 units
Saving	Packaging Area	Elimination of manually cutting the siren boxes	108,00 €	per 1.000 units
		Variable savings (per 1.000 units)	**700,16 €**	

The material and equipment prices given in the table are based on researched selling prices[1] [64] [58] [59] [65] [66] [67]. All of them are one-time payments, which are due when implementing the concepts. In addition, the labor cost for implementation is included. The Estonian labor costs are estimated to be 13,60 Euro per hour and are according to the statistical values by the European Statistical Office Eurostat [68]. The labor costs include the salary costs and non-wage costs, e.g., employer's social distributions. For example, the labor for implementing the proposals at the warehouse are calculated as according to calculation 7.1.

$$\text{Labor costs} = \text{Estonian hourly wage cost} \times \text{working hours for implementation} \quad (7.1)$$

$$= 13{,}60\ \frac{€}{\text{h}} \times 6\ \text{h} = 81{,}60\ €$$

One implementation – the removal of the door threshold – does not cost Defendec anything because the landlord does it. The listing was made for the sake of completeness. In total, there are ten fixed cost factors, which add up to almost 2000 Euro.

When it comes to variable cost, the packaging material for the siren might slightly increase in price when introducing a new design. The additional costs per 1000 units are based on the share of 108 sirens out of 1000 shipped units. The value for each Siren box had to be estimated because the final prototype is not ready yet. The corresponding calculation can be seen in calculation 7.2. Except for the packaging, there are no other variable costs, which affect the to-be concepts.

$$\text{Additional packaging costs} = \text{cost increase per pcs} \times \text{manufactured sirens} \quad (7.2)$$

$$= 0{,}70\ \frac{€}{\text{pcs}} \times 108\ \text{pcs} = 75{,}60\ €$$

The four different savings are all based on reduced time consumption when performing the task. Therefore, the Estonian labor cost of 13,60 Euro per hour was taken to calculate the savings. The savings due to better ergonomic working conditions are estimated and based on long-term savings from fewer employee sick days. The savings

[1] The research was conducted on May 5th, 2021 and reflects market prices as of that date.

amount to 700 Euro per 1000 shipped units. Figure 7.1 depicts all costs and savings from Table 7.1 graphically.

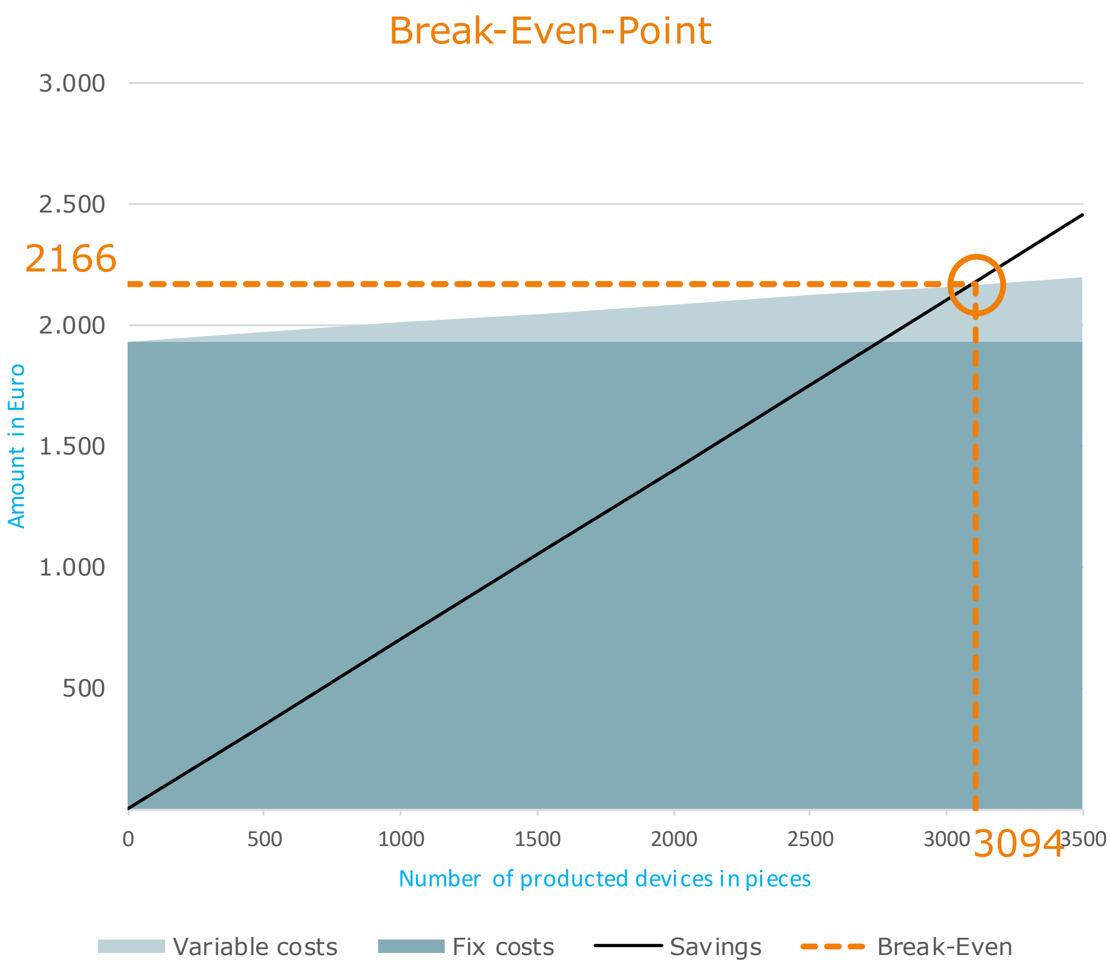

Figure 7.1 Break-Even Point Analysis

As depicted in the figure and according to calculation 7.3, the break-even point is reached after 3094 devices, leading to amortization in less than a year.

$$\text{Break-Even-Point} = \frac{\text{fix costs}}{\text{savings per 1000 pcs} - \text{variable costs per 1000 pcs}} \tag{7.3}$$

$$= \frac{1932{,}40\ €}{700{,}16\,\frac{€}{1000\ \text{pcs}} - 75{,}60\,\frac{€}{1000\ \text{pcs}}} \approx 3094\ \text{pcs}$$

The exact amount of time cannot be stated due to confidentiality reasons, as mentioned before. The calculations show that the improvements are economically feasible, profitable, and have a positive effect on the production of Defendec OÜ.

SUMMARY

Defendec's products and its production facility in Tallinn were introduced in the preceding chapters before an actual state analysis of the production was performed. For this purpose, the author evaluated and chose out of the explained lean tools the bottleneck analysis. The study itself was carried out by utilizing the modeling software Arena. The result indicated several bottlenecks, from which two – the warehouse and the packaging area – were solved within this paper.

The subsequent analysis of the two bottlenecks was conducted using Gemba and describing the detected issues with the lean tools seven wastes, 5S, and time and motion studies. In sum, the warehouse analysis showed that the components were not stored according to any system, and employees regularly searched for their needed components. Furthermore, it became apparent that the storage space was not sufficiently utilized because the parts were not stored within space-saving standardized boxes. The as-is analysis of the packaging area led to the finding of ten problems, leading to unnecessary motion and transport as well as to unergonomic workflows.

Regarding the warehouse, the author proposed to implement three main improvements:

- Standardize boxes and the shelve layer spacing according to the box sizes;
- Implement label holders at the shelves and the standardized boxes;
- Implement a color-coding system to differentiate product-specific components.

The packaging area improvements included the following:

- Exchanging the tables and changing the height of the scale for an ergonomic workplace;
- Establishing fixed locations for the components at the respective workplace to standardize working procedures;
- Redesigning the packaging of the siren device to eliminate manual cutting;
- Introducing tools like label dispensers and scales for faster and smoother processing.

Based on the framework conditions mentioned in the financial feasibility chapter, the proposed solution sets higher ergonomic standards for the production employees, lowers the overall production time by 45 hours per 1000 devices, and reduces the costs by 625 Euro per 1000 devices. The amortization of the proposals takes less than a year. The exact pay pack period cannot be published due to confidentiality reasons.

In a nutshell, the author and the company are satisfied with the results of the study. The objective of the work, detecting and solving production-related bottlenecks at the site of Defendec OÜ in Tallinn, was successful. The two concepts for the bottlenecks should be implemented promptly and then continuously optimized in a continuous improvement process.

In the follow-up to this master thesis, future research can clarify which improvements can be implemented at the other workstations. The thesis scope focused on the most severe bottlenecks, but improvements can be made anywhere within the production premises, leading to further time and cost savings. In addition, it is not foreseeable how the increasing sales figures will influence the production processes. For this reason, further research can be carried out.

KOKKUVÕTE

Magistritöö esimestes peatükkides tutvustati Defendeci tooteid ja Tallinnas asuvat tootmisüksust, millele järgnes tootmise hetkeseisundi analüüs. Selleks hindas autor selgitatud lean tööriistasid ja valis nendest välja nn pudelikaela analüüsi. Analüüsi läbiviimiseks kasutati modelleerimistarkvara Arena. Tulemus näitas mitmeid kitsaskohti, millest kahele - laoruumile ja pakkimisalale – leiti lahendus käesolevas töös.

Järgnevalt analüüsiti Gemba abil antud kitsaskohti ja kirjeldati tuvastatud probleeme järgnevate lean tööriistade abil: seitse raiskamise tüüpi, 5S ning aja- ja liikumisuuringud. Kokkuvõttes näitas laoanalüüs, et komponente ei ladustatud ühegi kindla süsteemi järgi ja töötajad otsisid pidevalt vajalikke komponente. Lisaks selgus, et laopinda ei kasutatud piisavalt efektiivselt, sest tooteid ei ladustatud ruumisäästvates standardiseeritud karpides. Pakkimisala olemasoleva olukorra analüüsi tulemusena leiti kümme probleemi, mis toovad kaasa tarbetu liikumise ja transpordi ning ebaergonoomilised töövood.

Laoruumi osas tegi autor ettepaneku rakendada kolme peamist parendust:

- Standardiseerida karbid ja riiulite vahekõrgused vastavalt kastide suurusele;
- Rakendada riiulitel ja standardiseeritud karpidel sildihoidjaid;
- Rakendada värvikoodide süsteemi, et eristada tootespetsiifilisi komponente.

Pakkimisala parendused hõlmasid järgmist:

- Laudade välja vahetamine ja kaalu kõrguse muutmine ergonoomilise töökoha eesmärgil;
- Tööprotseduuride standardiseerimiseks komponentidele kindlate asukohtade kehtestamine vastaval töökohal;
- Sireeni pakendi ümberkujundamine, et vältida pakendi käsitsi lõikamist;
- Tööriistade, nagu näiteks etiketijaoturite ja kaalude, kasutuselevõtt kiiremaks ja sujuvamaks tööks.

Tasuvusuuringu peatükis mainitud tingimustel toob pakutav lahendus kaasa kõrgemad ergonoomilised standardid tootmistöölistele, vähendab üldist tootmisaega 45 tunni võrra iga 1000 seadme kohta ja vähendab iga 1000 seadme puhul kulusid 625 euro võrra. Ettepanekud on finantsiliselt tasuvad vähem kui aastaga. Täpsemat tasuvusperioodi ei ole võimalik konfidentsiaalsusnõuete tõttu avaldada.

Lühidalt öeldes on autor ja ettevõte uuringu tulemustega rahul. Töö eesmärk, tootmisega seotud kitsaskohtade tuvastamine ja lahendamine Defendec OÜ tegevuskohas Tallinnas, oli edukas. Kahte nn pudelikaela kontseptsiooni tuleks koheselt rakendada ja seejärel ka pidevalt parendada.

Käesoleva magistritöö järelmeetmena on tulevastes uuringutes võimalik välja selgitada, milliseid parendusi saab rakendada teistel tööpostidel. Magistritöö raames keskenduti peamistele kitsaskohtadele, kuid parendusi on võimalik teha kõikjal tootmises, mis tooks kaasa veegi suurema aja- ja kulusäästu. Lisaks ei ole ette näha, kuidas kasvavad müüginumbrid tootmisprotsesse pikas perspektiivis mõjutavad. Mingil hetkel võib osutuda vajalikuks automatiseerimine. Seetõttu on võimalik teha täiendavaid uuringuid.

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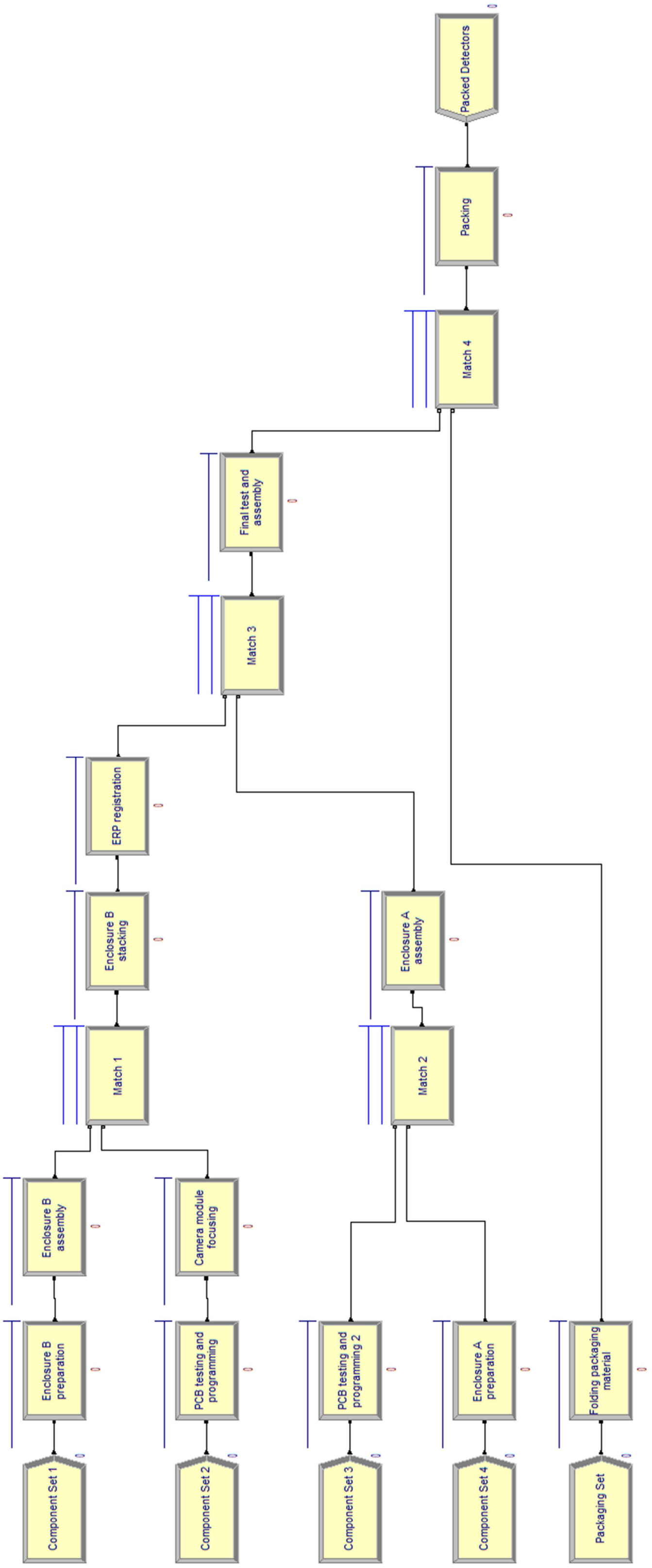
APPENDICES

Appendix 1: Arena Simulation Model



GRAPHICAL MATERIAL

Graphical Material 1: Label Drawings for the Warehouse Concept