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

PRODUCTION LAYOUT DESIGN AND STANDARDIZATION IN DEFENDEC OÜ

DEFENDEC OÜ TOOTMISE PÕHIPLAANI KUJUNDUS JA STANDARDISEERIMINE

MASTER THESIS

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Tallinn 2021

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THESIS TASK

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Thesis topic:

(in English) Production Layout Design and Standardization in Defendec OÜ

(in Estonian) Defendec OÜ tootmise põhiplaani kujundus ja standardiseerimine

Thesis main objectives:

1. Redesign production layout to shorten product flow
2. Develop a concept for workplace layout
3. Propose improvements for standardization and increasing efficiency
4. Find the break-even point of implementing a new production layout

Thesis tasks and time schedule:

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2.	Theoretical overview	05.04.2021
3.	Current process analysis	19.04.2021
4.	Production layout design and standardization, improvements for the production premises	03.05.2021
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PREFACE

The current master thesis was initiated by Rene Lõhmus who works as a head of manufacturing in Defendec OÜ. The current production layout and premises have become insufficient as the production volumes have grown more than ten times during the last couple of years. As the company has an opportunity to rent additional premises for production then it necessary to analyse the production processes and design a suitable layout for the new premises.

The author would like to thank the team of Defendec OÜ who shared information and thoughts about improvements in production and gave input to the master thesis. In addition, many thanks to professor Kristo Karjust for supervision throughout the thesis.

Keywords: layout design, standardization, improvement, master thesis

List of abbreviations and symbols

ERP – Enterprise resource planning

ESD – Electrostatic discharge

IoT – Internet of things

KPI – Key performance indicator

PCB – Printed circuit board

WIP – Work-in-progress

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INTRODUCTION

Defendec OÜ is an Estonian company that develops and manufactures surveillance systems based on smart dust technology. Within the last couple of years, the production volumes have grown more than ten times. As a result, the current production premises have become too small and insufficient to cope with the increasing demand for the products. As the company has an opportunity to expand its production to new premises inside the building, it is necessary to analyse the production processes and layout in order to develop and design a more efficient new production layout.

The main objective of the master thesis is to design an efficient production layout for the production premises. It includes the following points:

1. Redesigning the production layout to shorten product flow and component movement;
2. Developing a concept for workplace layout;
3. Proposing improvements for standardization and for efficiency increase;
4. Identifying the break-even point of implementing a new production layout.

An overview of the company, its main products and production is given in the first chapter. Additionally, the reason why the production volumes have started to increase during the last couple of years and why the production process analysis is necessary are explained. Next, theoretical background is introduced. Different process and layout types are explained together with useful tools that support the layout efficiency when implemented properly. The third chapter focuses on the current production processes and layouts of the three main products of the company – detectors, bridges and sirens. The production processes are described and their peculiarities explained. Moreover, the values of key performance indicators of the layout are identified. The production process and layout of detector production are more deeply analysed with Siemens Tecnomatix Plant Simulation software since it is the product with the highest production volume. In the following chapter, the new production layout is designed and explained. The KPI-s of the new layout are identified and compared with the KPI-s of the current layout. In addition to that, a general workplace layout concept is developed. The author suggests several improvements that enhance the production efficiency.

Finally, a break-even analysis of the new production layout is conducted to evaluate the financial feasibility and the results of the master thesis are presented in the summary. It is important to mention that the outcome of the thesis will be used when expanding the production department to new premises.

1 OVERVIEW OF DEFENDEC OÜ

Defendec OÜ is an Estonian company that is mainly engaged in developing and manufacturing wireless surveillance systems. The company manufactures perimeter and site surveillance devices based on smart dust technology. Smart dust is a system of small micro-electromechanical devices that are connected wirelessly and can gather all kinds of data such as temperature, light and sound. In Defendec's case, the technology allows to monitor a certain area from afar via computer. The main customers of Defendec are different defence and border guard units of countries, security companies and infrastructure companies. More than 90% of the production output is being exported. The company has sold and deployed its products to more than 30 countries around the globe – to every continent except Antarctica. Defendec is also a member of the Estonian Defence Industry Association. In 2015 Defendec was elected as the Estonian defence company of the year.

Figure 1.1 Countries where Defendec devices are deployed [1]

The company was founded in 2006 as a start-up company named Smartdust Solutions OÜ. The founders were three friends who, instead of working on the basis of employment contracts for the other companies, had a wish to do something big and meaningful by establishing their own company. The owners saw big potential in wireless sensor networks and started to develop different applications and products based on IoT. They tried counting cars, identifying water and gas leaks from pipes, developing intelligent traffic signs that could display real time data of road conditions, e.g. ice on the road. However, none of these applications were successful at that time due to lack of interest and demand. After a while the company managed to form a partnership with the Estonian Police and Border Guard Board that was determined to get a better overview of activities on borders of the country and was willing to try smart dust technology. As a result the company developed rapidly deployable wireless surveillance systems that gave the border guards virtual eyes over the state border. The first sensor for border surveillance was released in 2009. In 2010 the company was named to Defendec OÜ and it focused mainly on developing and manufacturing wireless surveillance systems. Since then the company has constantly innovated the defence and security perimeter protection meaning and automated border protection, law enforcement and security processes. The products of Defendec are currently also being used on the Estonian-Russian border, making the Estonian Police and Border Guard Board a beneficial reference customer to the company which also plays an important role in the later success story of the Defendec.

Defendec is on the market with 2 surveillance system solutions – Smartdec and ReconEyez. First of them, Smartdec, is a surveillance system solution which was originally developed in cooperation with the Estonian Police and Border Guard Board and is focused on the defence and border guard sector. The customers of Smartdec are mainly different defence and border guard units of countries. Smartdec helps to stop and prevent illegal border crossing and trafficking, international smuggling and other acts of sabotage. The solution is being used for securing European Union's and NATO's external borders [2]. Smartdec includes selling the product and offering support services, for example system deployment on the field, server installation and product training for end-users. The sales cycle of Smartdec is usually long, spanning over several years from the first meeting and presentation to closing the deal. Sales are made through direct contacts or in cooperation with partners who operate in the target market and are aware of the market peculiarities. The sales process of Smartdec usually requires participation in public procurement procedures that have a high level of bureaucracy. As each Smartdec project is slightly different and unique, it needs some special development and investments. The products are sold with a one-time price which means that cash inflows to the company are infrequent. Sales are usually made in the end of the year as different defence and border guard units spend the money left over in the budget.

The second business model, ReconEyez, is similar to Smartdec. ReconEyez helps to stop and prevent theft, terrorism, trespassing, fly dipping and could also be used for process monitoring, e.g. truck turnover time in construction sites and terminals. The customers of ReconEyez are private companies such as security companies and infrastructure companies. The solution is being used, for example, in construction, energy, mining, void property and transportation industries [1]. Besides selling the products and having monthly subscription per device for using Defendec-hosted servers, it is also possible to rent the devices. Reconeyez business model is more easily scalable compared to Smartdec business model. The main markets for ReconEyez are United Kingdom and Western Europe but the aim is to also enter the US market in the near future.

As mentioned, Smartdec is a business with one-time fee if a company manages to win a procurement. However, the procurement processes of the countries are not frequent and due to volatile environment in the defence sector, Defendec decided to change its strategy. In fact, in the end of 2017, couple of procurements that the company was aiming to attend were cancelled or postponed and it put Defendec into a difficult situation. Moreover, the company’s turnover was in decrease for a couple of years. In order to be more sustainable as a business, a change in strategy was made during 2018 under the renewed management. The aim of the strategy change was to increase the company's efficiency, scale the business in commercial markets with monthly fee-based services and reduce the number of project and procurement-based sales. Since 2018 the company focuses on commercial markets by selling ReconEyez solution to private companies. This market is easier to forecast and the cash flows are more stable. In addition to that, the Reconeyez business model with monthly subscription fees has higher growth potential. The company has set its directional strategy towards growth, aiming to expand its activities through horizontal growth – mainly by focusing on export at the moment. In addition to exporting through foreign partners, Defendec works towards establishing its own sales companies abroad to have better control in the area.

After the strategy change, the company was challenged to adapt to the expectations of the commercial market. For being successful, process reengineering was carried out. Compared to the national security markets, the commercial security markets are more price-sensitive and with the expectation on very short lead times. Private companies do not want to have big stock regarding security cameras, rather they expect to have the items delivered immediately if the need is raised by their customers. Moreover, as security and infrastructure companies aim to be as cost effective as possible, the operating cost and automation level of a surveillance system are also important aspects to be considered. For example, if a system is highly automated, there is no need for human labor and this helps to reduce costs.

Defendec operates globally, having offices in Estonia, United Kingdom and United States of America. The main office is located in Tallinn, Erika 14, on the 2nd floor of Arsenal Center, where all departments are functioning together. Defendec has an in-house hardware and software development and production which enables shorten development and product launch cycle. In the beginning of 2021, there were 27 employees working for the company. Defendec has a functional structure, which is common to small and medium-sized companies. The company is divided into 4 main departments that are displayed in Figure 1.2. Each department has its own tasks, short-term objectives and key performance indicators which are being measured.

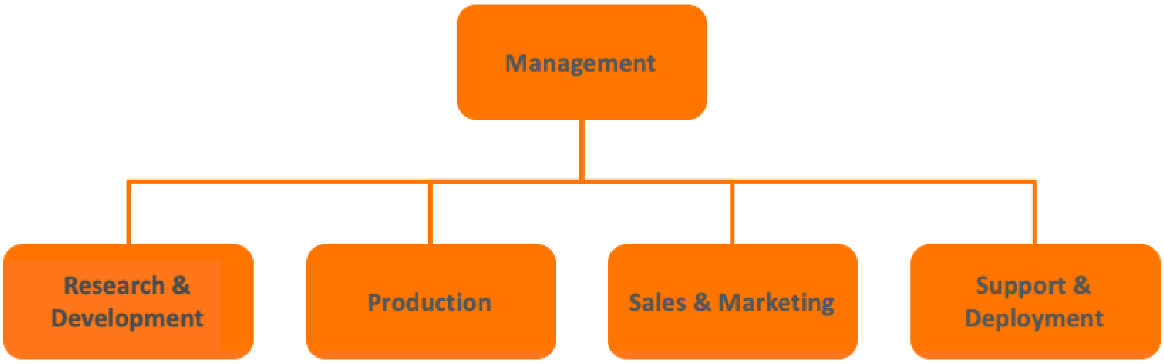


Figure 1.2 The structure of Defendec OÜ

Defendec, together with its subsidiary and parent company (with its other subsidiaries), forms a bigger group, whereas only Defendec is the company that develops and manufactures the wireless surveillance devices. In addition, it offers repair and maintenance services. The annual revenue and operating profit of Defendec between 2010-2020 is displayed in Table 1.1.

Table 1.1 The revenue and operating profit of Defendec OÜ from 2010-2020 [3]

Year	Revenue (€)	Operating profit (€)
2010	205 880	37 006
2011	340 449	- 504 278
2012	658 309	-396 134
2013	1 010 046	-625 058
2014	2 143 796	464 687
2015	977 525	-671 198
2016	2 164 442	318 351
2017	1 542 781	-686 888
2018	668 500	-673 072
2019	1 903 073	-38 976
2020	2 758 775	-69 891

Based on the financial information displayed in Table 1.1, it can be seen that annual revenue of Defendec has been steadily growing between 2010 and 2016 with an exception in 2015. On the other hand, the company has generated mainly operating loss during this period. This is due to the fact that, as a new manufacturer and supplier entering new markets, it is difficult to make the company visible in the defence market. Moreover, based on the market need and feedback, the company developed and improved their products, all of which needed big investments. As mentioned before, each Smartdec project is slightly unique, meaning that more development resources are needed. Also worth mentioning is that usually the sales processes in the defence sector might take several years, often with the need for many meetings and coordination with the potential customers as well as much travelling and many site surveys for potential deployment areas. In terms of operating profit, 2016 has been the most successful year for Defendec so far. The reason for that is winning a high valued tender which deployment lasted all throughout the year.

During 2010-2017, the company focused on selling Smartdec solution to the defence sector. As this sector is highly volatile and unstable due to its peculiarities, the company’s turnover was in decrease during 2016-2018. 2018 was the year during which the change in strategy was made. This explains the poor financial performance of 2018 as the main focus of the company was its reorganisation. After carrying out an analysis of the security market situation and the strategic factors of the company, Defendec found its place and strengths which it managed to implement successfully – long battery lifetime and artificial intelligence. Since then the production volumes of the company have doubled each year [4]. However, the production growth is not fully reflected in the financial indicators of Defendec. It is true that the annual revenue has grown but these numbers do not include the monthly subscription fees. In fact, all the products that are manufactured by Defendec are sold to end customers through group subsidiaries. In addition, as the commercial market has different needs compared to the border guard market then the company redesigned its products, developed new additional products and software suitable for the commercial market. Defendec also had to adjust its operations, logistics and purchase strategies in order to meet the market need. This all needed investments, therefore, the company still generated operating loss after the change of strategy, which is, however, lower than previously. In sum, the financial performance has improved in recent years, meaning that Defendec is following the right path.

1.1 Product Description

All products of Defendec are designed, developed and manufactured in-house or in cooperation with production partners and sub-contractors. These include wireless security cameras, battery chargers, handheld devices, fastening units etc. All devices of the perimeter surveillance system are rugged, high-tech, military standard devices that can be used in different climate conditions. The operating temperature range for the devices is -40°C to +60°C. They have an ingress protection rating 67 (IP67) and tough enclosure. IP67 refers that the enclosures of the devices are dust-tight and waterproof under 1 meter deep water for 30 minutes [4]. By default the enclosures are coloured navy green but there are other colours also possible, even waterprinting different patterns onto the enclosures. The devices are powered by 10,2 Ah rechargeable lithium-ion batteries but additional other power methods are available, e.g. solar panel or battery extension pack added to the devices that prolong the battery lifetime. Under average conditions, with fully charged batteries, the devices can function up to 400 days or up to 50 000 photos, however, the exact battery life depends on several factors, including signal quality, image quality and number of events sent. There are 3 main products of Defendec – detectors, bridges and sirens. These devices can be installed and configured rapidly within 2 minutes. The detectors and bridges were developed in cooperation with Estonian Police and Border Guard Board. The development and launch of the sirens was triggered by the need of the commercial market after the strategy change of Defendec. All of Defendec's technology is patented [2]. Moreover, the devices are affixed with a CE (*Conformité Européenne*) marking, meaning that they meet the high requirements of safety, health and environmental protection within the European Economic Area [5].

Detector is a small, autonomous, intelligent wireless sensor to monitor the environment and make decisions about possible threats. It is triggered by motion detection or tamper sensor but it can also be activated at preconfigured times set by an operator. The product uses passive infrared (PIR) sensor and signal analysis to track movement. With its sensors, detectors can gather all kinds of information, for example, movement, temperature, date and time. The product weighs approximately 0,7 kilograms and its dimensions are 9 x 12 x 10 cm. The aim of the detector is to register any movement in the monitored area and send information about it to the server. It can detect movement from 35 meters and can capture it with full high-definition day and night cameras. Quality of photos is configurable. The detectors are equipped with infrared flash – it helps to light the monitored area in darkness and it is not visible to the human eye. The detectors are equipped with 2,4 GHz short range radio for two-way communication between devices that can spread up to 500 meters in case of line of sight. The visual appearance of a detector is displayed in Figure 1.3.

Figure 1.3 Visual appearance of a detector

Bridge is an autonomous, battery powered, multi-frequency communication device equipped with a 4G module for long range communication and a short range radio (2,4 GHz). The aim of the bridge is to forward all the data from connected devices to the command centre server via GSM signal. One bridge can support up to 8 devices – detectors and sirens – under average conditions. The product weighs approximately 1,4 kilograms and its measures are approximately 9 x 8 x 30 cm (44 cm with antenna). The bridge uses 4 rechargeable lithium-ion batteries for power. The battery life depends on signal strength, number of devices connected to it and number of events sent to the command centre. The visual appearance of the bridge is displayed on Figure 1.4.

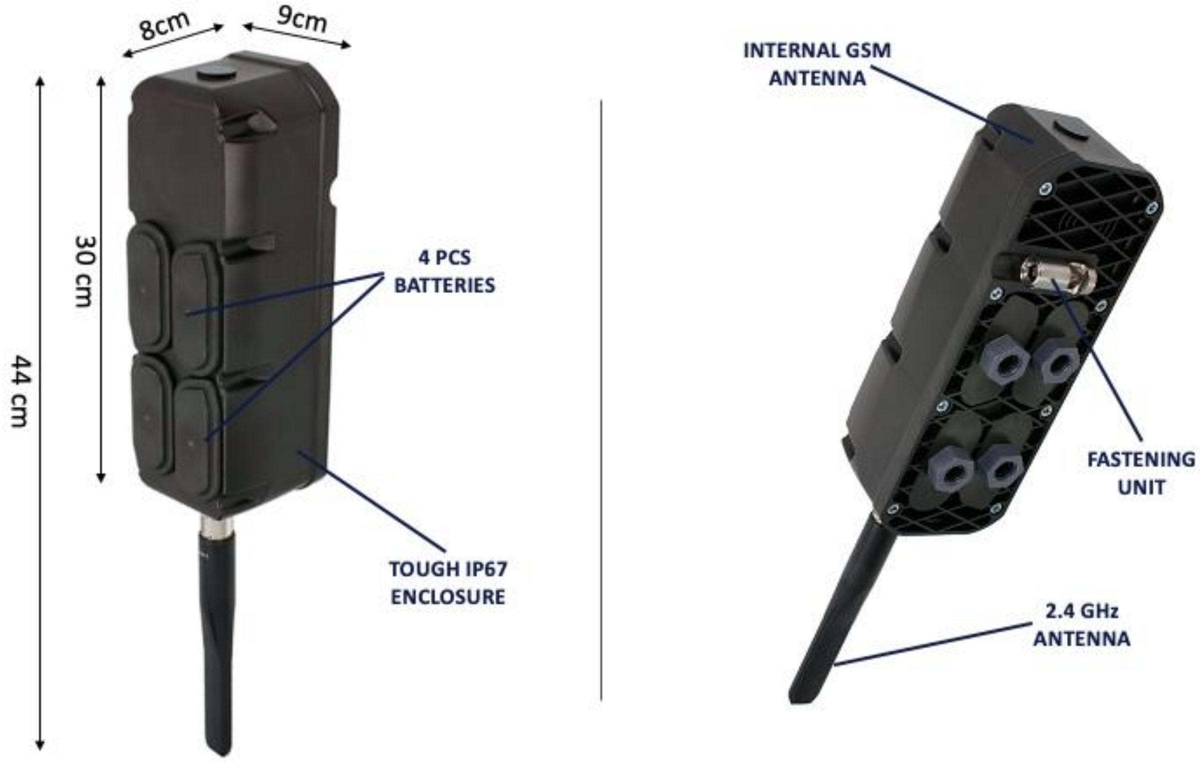


Figure 1.4 Visual appearance of a bridge

Siren is an audible and visual alarm indication device to announce an alarm condition within the monitored area. The sirens are used for the purpose of deterrence. If an operator sees from command centre that a certain area they are monitoring is being trespassed, then they can activate the siren. As a result, the siren's beacon starts to flash and gives a loud alarm with over 90 dBm. The product weighs 1,5 kilograms and its measures are approximately 9 x 8 x 36 cm (50 cm with antenna). As the siren is developed based on the bridge's enclosure, then it can also fit up to 4 rechargeable lithium-ion batteries. In reality, it only needs one lithium-ion battery to work and the rest of the battery slots could be filled with dummy batteries. The battery life depends on the signal strength and the number of alarms activated. The visual appearance of the siren is displayed in Figure 1.5.

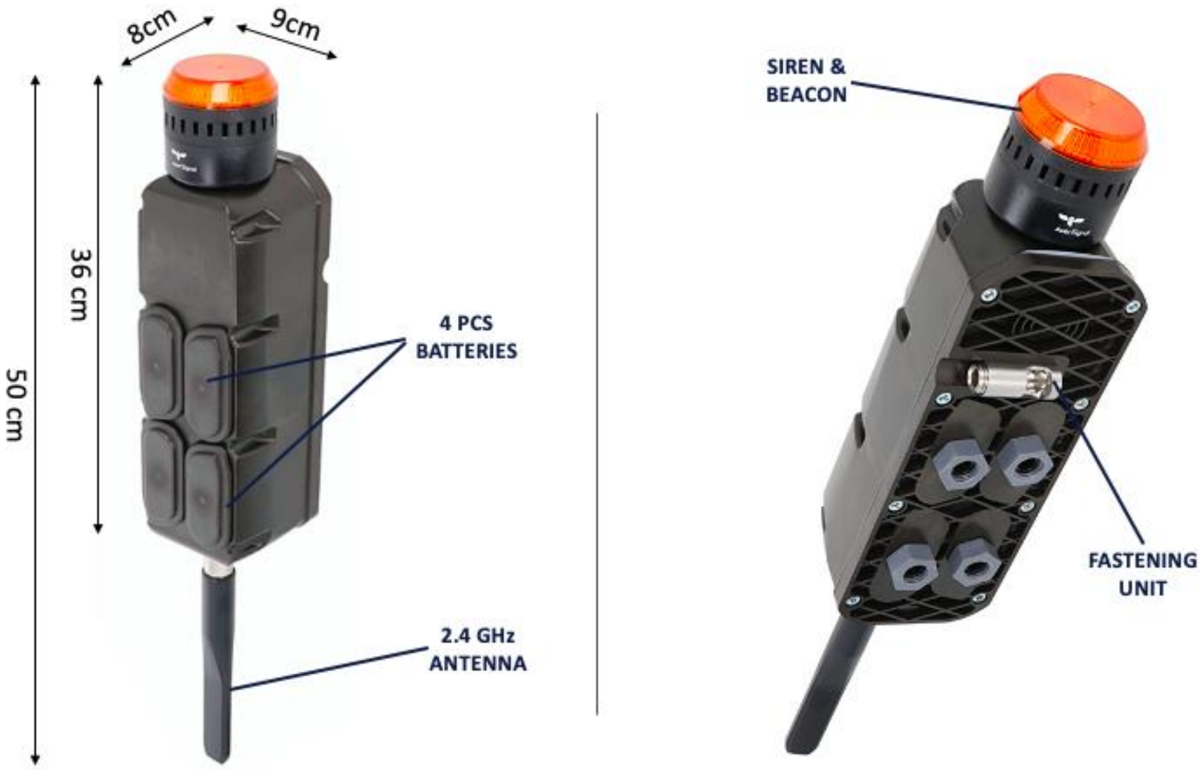


Figure 1.5 Visual appearance of a siren

The detectors, bridges and sirens communicate to each other over a low power mesh network which supports up to 8 hops. It means that if a detector or a siren cannot connect directly to the bridge for some reason, then the data is sent to the bridge through other detectors or sirens. If a detector's patented algorithm detects intruders, then an alarm is triggered and photo(s) are taken. This data is sent to the command centre through the 4G bridge. The distance between the bridge and the command centre is unlimited as the data is sent via GSM network. The received photos are analysed by artificial intelligence which classifies recognised objects on the photo into predefined categories, e.g. a person, car, bicycle. As a result of received data, the command centre operators decide whether to react to these alarms or not.

Defendec's surveillance system has several benefits compared to the regular CCTV (closed-circuit television) solutions. Firstly, the system is almost maintenance free and autonomous. It does not require additional infrastructure – a regular tree, wall, post etc. for installation, while CCTV needs additional electricity and cabling. Secondly, the system optimizes and automates law enforcement, border protection and security processes. Instead of command centre operators constantly monitoring security cameras, which might be unreliable, Defendec's solutions alerts the command centre only in real alarm cases. Therefore, the system increases resource utilization for its customers, saving time and money.

1.2 Production overview

The production unit of Defendec not only manufactures new devices but also carries out maintenance and repair works of returned devices. Moreover, since Defendec does not have separate units for procurement, purchasing and logistics, then these functions are also currently under the production unit. As of the beginning of 2021 there are 4 full-time employees in production unit – production manager, production assistant and two production specialists. In addition, there are 5-6 part-time production workers available that can be called for help during busy production periods. They mainly work on the weekends or later in the evening on working days which gives the flexibility to adjust the production capabilities according to needs. On the other hand, it is a bit more difficult to plan the production resource-wise and it needs more communication as the part-time workers have other duties as well and might not always be available when additional labour is needed. The production specialists are responsible for testing, assembling and packing the products, filling in the necessary production information about device serial numbers, ID numbers and configurations into the ERP system and carrying out maintenance and repair works if necessary. The main duties of the production manager are production management, planning and quality assurance in the production process. In addition to that, he is also responsible for sourcing and supply chain. On the one hand, managing both the production and sourcing is a positive aspect as, due to that, the production manager has a good overview of everything. On the other hand, this does not allow the production manager to focus on a certain matter. The main duties of production assistant are managing production documentation, storage room and communicating with transportation partners.

As mentioned previously, the production area of Defendec is located on the 2nd floor of Arsenal Center. In order to reach the production area, there is approximately 40 meter distance that has to be covered, including approximately 20 meters of stairs. There is no elevator meaning that incoming and outgoing goods are carried manually up and down the stairs.

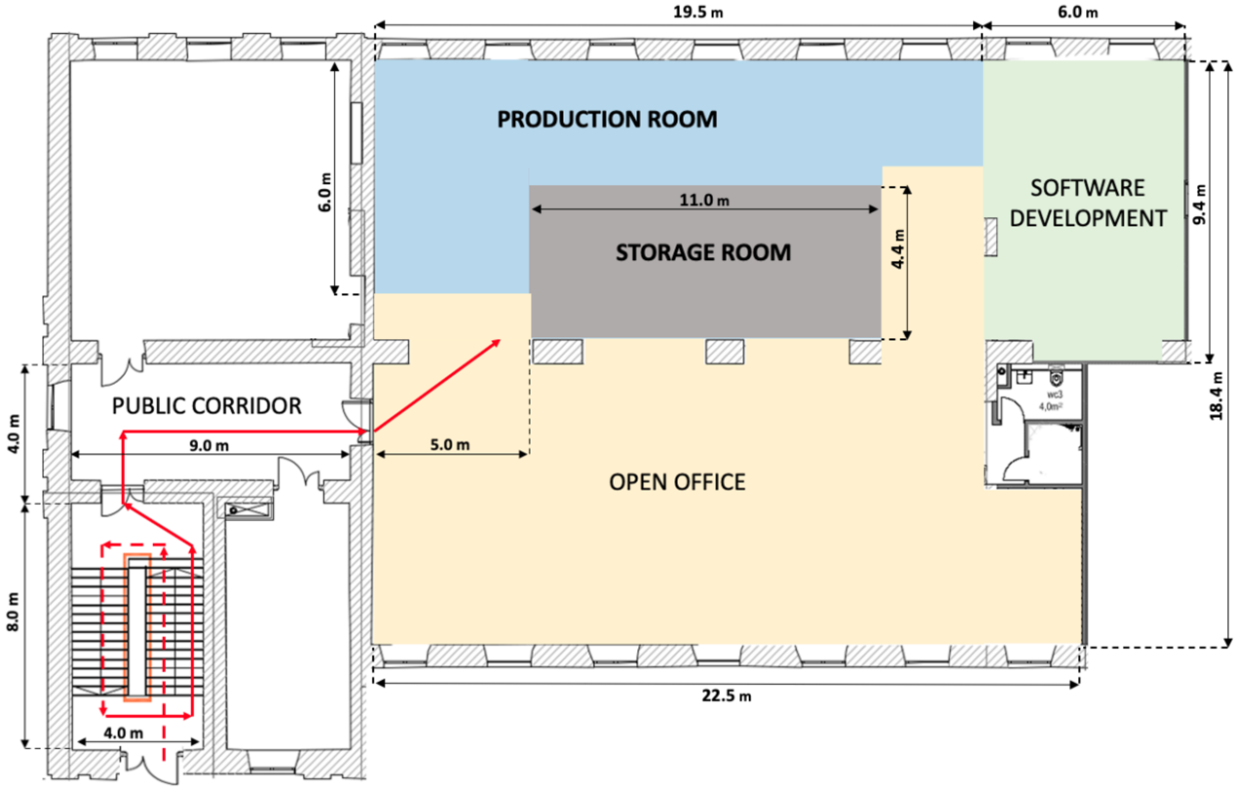


Figure 1.6 Route to production room (As Is)

Currently the production room is shared together with hardware and support teams which means that some of the workstations are common, e.g. the soldering workstation. A positive side of it is that information and feedback moves quickly between the units. On the other hand, at some point, the separate units might disturb each other since there is not enough space. The storage room is located next to the production area. Besides storing components for production, the stock also has a separate area for storing support and deployment, development and marketing items. Additionally, some testing of the PCB-s is also carried out in the storage room. The layout of the production premises is displayed in Figure 1.7.

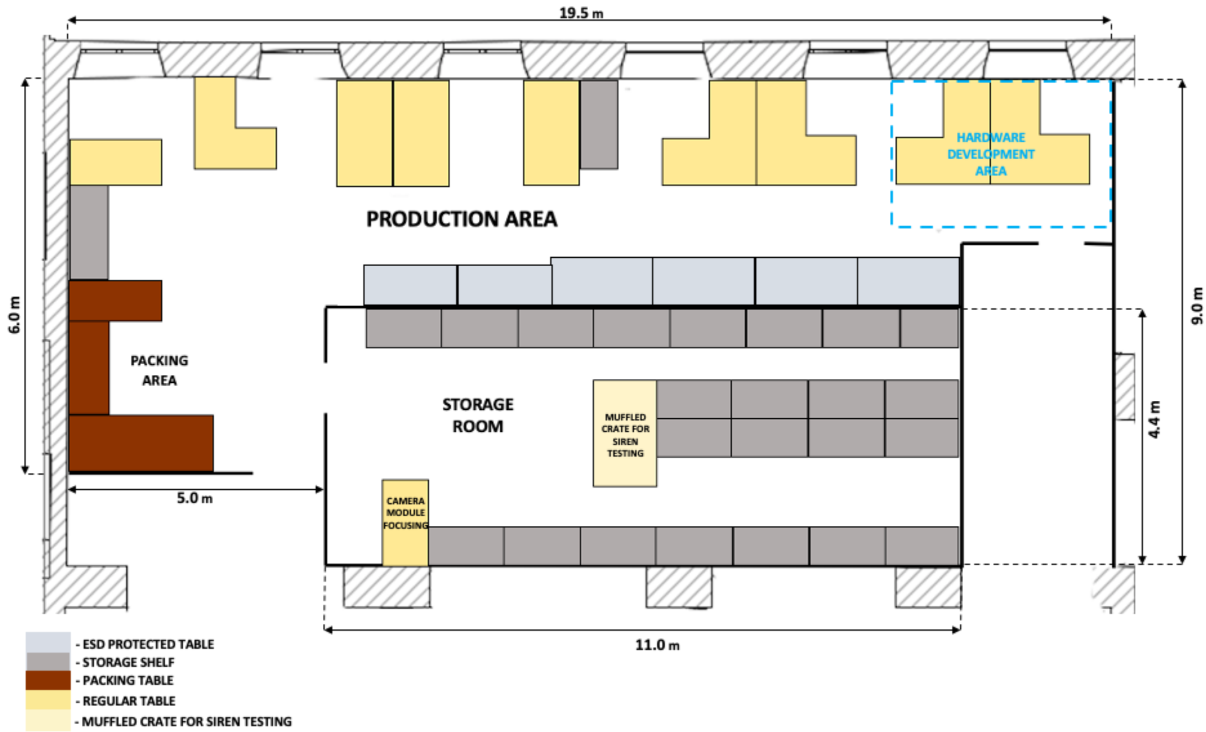


Figure 1.7 The layout of production premises (As Is)

The assembly of the detectors, bridges and sirens is done manually using cordless screwdrivers. The components used in the assembly process are mainly standard components that can be purchased or special parts that have been self-designed and are produced by the sub-contractors. At first, most of the self-designed parts used in production were also made in-house. Over time, the production of simple parts and sub-assemblies has been outsourced to sub-contractors. This has enabled Defendec to save time and focus on testing and final assembly which ensures better quality of production. The special equipment included in production are various testers and programmers. As the products also include electronics then there are ESD protection measures implemented in the production room. For example, the flooring is made from special groundable material, ESD footwear is worn, workstation tables are groundable or covered with ESD mats. If ESD protection measures are not applied, the PCBs may malfunction as a result of electrostatic discharge.

The initial detectors and bridges were developed together with the Estonian Police and Border Guard Board on engineer-to-order (ETO) principle, meaning that the devices were specifically developed based on the need for an autonomous wireless surveillance system. Before the strategy change in 2018, the production was carried out based on the make-to-order (MTO) principle. This means that the production is started only when an order is placed by a customer. There is no production to stock of finished goods until demand arises. A disadvantage of make-to-order production may be the fact that products may not always be delivered to the customer on time [6]. After the focus shift to the commercial markets, the production volumes have grown more than 2 times annually. As a result, orders have become more frequent which gives stability to the company. Consequently, Defendec shifted its production from make-to-order to assemble-to-order (ATO) principle. It means that the products are usually prepared and the final assembly takes place when an order is received from the customer. Compared to make-to-order, the advantage of assemble-to-order is the increased ability to ship the goods to customers more quickly. However, compared to make-to-stock (MTS), the disadvantage of this production principle is the fact that products may not always be delivered to customers as quickly as requested and the lead time is longer than the industry average in security market where products are shipped straight from stock [7], [8]. On the other hand, as the products are developed constantly, it is not in the interest of Defendec to have large stock of products which is not also possible due to the current capabilities of the company. Another reason why the production is carried out on assemble-to-order principle is due to the production peculiarity. To be exact, each customer has its own security certificate that has to be loaded onto devices. Therefore, the devices cannot be assembled and packed before a certain customer order has been received.

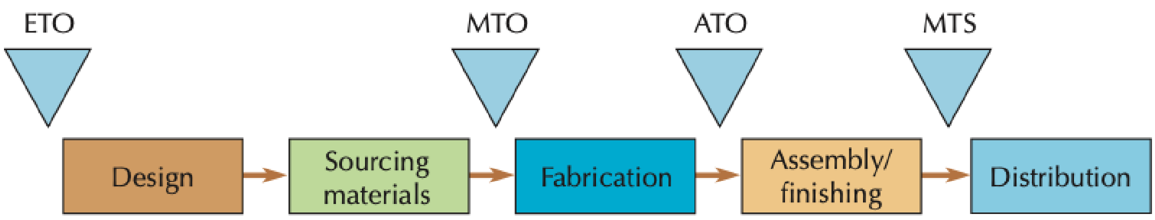


Figure 1.8 Customization points [7]

In terms of the volume and variety of the production process, production process of Defendec can be classified as a batch process. Therefore, more than one product is produced at a time – items are produced in batches. The bigger the batch size is, the more repetitive the process can be. Regarding process flow and tasks the batch processes are somewhere in between of intermittent, diverse and continuous, repeated. To take an example from Defendec, newly arrived PCBs are tested all together few times a month, a certain quantity of enclosures are assembled at once etc. As the production room is getting a bit small for the production volumes then there are certain workstations evolved where certain tasks are carried out. Based on that, the layout of the production room can currently be classified as a functional layout. All process steps are done in workstations that have the necessary equipment and similar resources are grouped together. For example, the PCBs are tested at a table that has a computer and testers, packaging takes place in a certain area etc. The advantages of functional layout are its flexibility and the simplicity of managing resources and the resistance to process malfunctions. On the other hand, it is more difficult to manage process flow and it has a lower facilities' utilization level [9]. The work-in-progress is stored on tables, shelves or on carts that can be moved around the production area. In addition to that, the carts are used for transporting the components from the storage room to the workstation and vice versa.

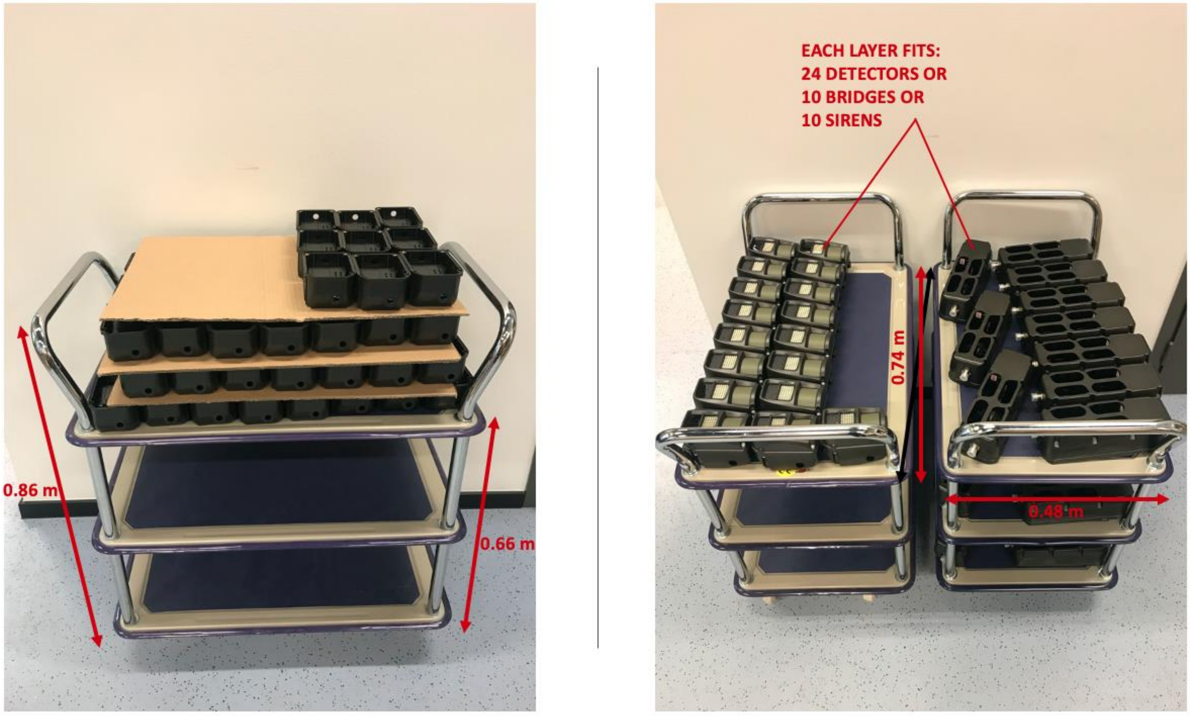


Figure 1.9 Carts used to store and move WIP and finished goods

Defendec has an ISO 9001:2015 certification which proves the quality of manufacturing, deployment and development. This certification specifies the requirements of the quality management system of a company. In short, having an ISO 9001:2015 certificate indicates that an organization is able to constantly provide products or services that meet the requirements of customers and applicable statutes and regulations and enhances customer satisfaction through the use of the quality management system [10].

It is written in the quality manual of Defendec that production is a two-step process which consists of purchasing components that can be considered as the preparation phase and production of devices. Purchasing is the first production step during which all necessary components for production are sourced. It includes constant communication with manufacturers and suppliers, negotiating of supply agreements, price negotiations, analysis of quality and availability of components. Periodic analysis of components in stock is carried out, contracts are signed with existing and new suppliers. Moreover, purchase orders are generated and their fulfilment is monitored. The conformance of received goods is checked and they are stored in the storage room. The main objective of the purchase process is to ensure the uninterrupted operation of the production. During the production process itself the incoming PCBs are inspected and tested, devices are assembled, programmed and configured according to the specification in the customer agreement. After passing successful final tests, the products are packed with accessories and labelled for transportation in accordance with the customer order [11].

The detectors, bridges and sirens consist of many different components – electronic modules, enclosure parts, seals, bolts and spacers, cables, antennas etc. All PCB-s received from sub-contractors need testing, programming or both for which the production unit has special testers and programming tools. If the electronic modules pass the tests then they can be used in later assembly process, otherwise, they are set aside for fault detection. The testers are easy to use – they display text on the computer screen whether the PCB passed the test or not. Currently most of the testers are held only by Defendec and testing is done in-house but the company aims to improve the testers and give them to sub-contractors that manufacture the PCB-s. In that way, the factories could test the modules and solve possible quality issues by themselves. As a result, defective PCB-s would not reach Defendec at all.

Parameter	Value
Dimensions	38 x 28 x 28 cm
Weight	10.8 kg
Cassette changeover time	30 s
Max size of PCB	20 x 20 cm
Number of axes	1 (vertical)

Figure 1.10 Tester used in production

Currently one of the main issues is that the production premises are located on the second floor where is no elevator access. There is a 40 meter distance, including 20 meters of stairs, to the production premises, meaning everything is carried manually up and down the stairs. Smaller shipments and packages are carried by the courier. However, when components are arriving in bigger quantities or a bigger order is being shipped then the production team stops their activities and also helps the courier with carrying. Obviously, it is not reasonable nor efficient from the production perspective. Moreover, there is too much unnecessary movement up and down the stairs which takes a considerable amount of time that could be used elsewhere.

The current production layout was designed and implemented in 2018. Since then the production volumes have grown more than 10 times. Now Defendec ships more devices in a month than it did annually couple of years back. The number of production employees has increased from 2 full-time and 1 partial time to 4 full-time employees and 5-6 part-time production workers. The production premises which are shared together with hardware engineers and support engineers, are getting a bit small as there is not enough room. The WIP is often moved one from place to another to free up space for a certain operation which can lead to components falling to floor and get defects. Therefore, it has been identified that the production layout does not meet the future plans and requirements of the company and it is not efficient. Defendec is planning to rent additional premises for production on the first floor of the same building in order to increase its production capacity and efficiency. Thus, the production processes of detector, bridge and siren manufacturing must be analysed in order to design a new and efficient production layout for the new production premises. In addition to that, complementary lean tools are suggested to be implemented to enhance the layout efficiency, standardization and sustainability.

Poor layout design is one of the major causes of inefficiencies in production [12]. Layout planning can be categorized into 3 levels: the layout of departments, the layout of facilities inside the department and the layout of individual workplaces. The current thesis focuses on analysing the layouts of facilities and workplaces in Defendec production premises. Planning a new layout is process where many different aspects must be included, e.g. the demand for the products, capacity determination, work methods and standards, resource and equipment requirements etc. In addition to that, lighting, noise, temperature, safety legislation and anticipated development are factors that affect the layout design [13].

2 THEORETICAL OVERVIEW

2.1 Process types

Processes involve using an organization's resources to create value – products or services. In general, processes can be divided into two – service and manufacturing processes which differ from each other on the nature of their output and level of customer contact. Manufacturing processes convert materials into products by transforming the physical properties, size, shape, surface finish of the material or joining parts and materials [8]. All processes vary on the range of volume and variety. These two process aspects usually go together but in a reverse way. In other words, on average a low-volume process tends to produce a high variety of products or services and vice versa – high-volume processes usually produce a low variety of products or services. Therefore, the design of a process should depend on the volume and variety it is planned to produce. Based on the volume-variety characteristics, a process can be differentiated into several process types. The number of different process types varies depending on the literature but most commonly 5 process types are differentiated: [9] [14]

- Project processes;
- Jobbing processes;
- Batch processes;
- Mass processes;
- Continuous processes.

It is important to mention that, in reality, the boundaries between the process types are not so clear. Moreover, products life cycles often start with low volumes which increase over time. In these cases process type should be looked over from time to time and be adjusted if necessary.

Project processes are nonroutine and have a low volume and high variety. The product dealt with is usually highly customized, unique and has a quite long time-period from start to finish. The product does not move around the production premises, it is stationary. In fact, the materials, equipment, human labour etc. are brought to the process site which needs a high level of coordination. Example of project processes are most construction works, e.g. ship building and bridge building [9], [14].

Jobbing processes tend to operate on a relatively small scale. These processes also have a low volume and high variety. However, jobbing processes share the operation's resources with others, while project processes have resources specially dedicated to them. Due to high level of customization the processing is intermittent and work includes small jobs that slightly differ from one another. The equipment used in jobbing processes is flexible and often involves skilled workers [14]. Companies that use jobbing processes do not produce to stock as they tend to bid for work and handle each order as a new job. Examples for jobbing processes would be furniture restorers and specialist toolmakers [15].

Batch processes are the most common process type used in practice. On the scale from low to high, both the volume and variety are positioned in the middle. As the name indicates, batch processes produce in batches. Depending on the batch size it can be similar to jobbing processes if the batch size is very small or very repetitive if quantities are bigger [9]. The processing is still intermittent, however, the equipment does not need to be so flexible nor the workers very skilled as in jobbing processes due to lower variety in the jobs being processed. As an example for batch processes is a bakery which makes pies in batches or machine tool manufacturing which manufactures special components in batches. The current production process of Defendec can also be categorized as a batch process.

Mass processes deal with items in high volume and quite narrow variety. In some literature, mass processes are also called line processes and repetitive processes. Mass processes are often associated with assembly lines. Since the volumes are high, then the products are generally standardized [8]. This allows to devote resources directly around certain products. Therefore, the need for flexible equipment and skilled labour is low. Equipment for production and material handling is specialized. Little inventory is held between different processing steps as divergence is minimal in the process flow. Standard products are produced to stock to ensure fast shipping once customers place orders. Examples of this process type are automotive industry and home appliances production [16].

Continuous processes have the highest volume and lowest variety out of all process types. As the name implies, the output is being produced continuously in an endless smooth flow. There is no need for equipment flexibility due to low variety, however, the process technology can be very expensive. The production is highly standardized. The need for skilled labour is dependent on the complexity of the production system. Examples of continuous processes are water processing and production of petroleum products [17].

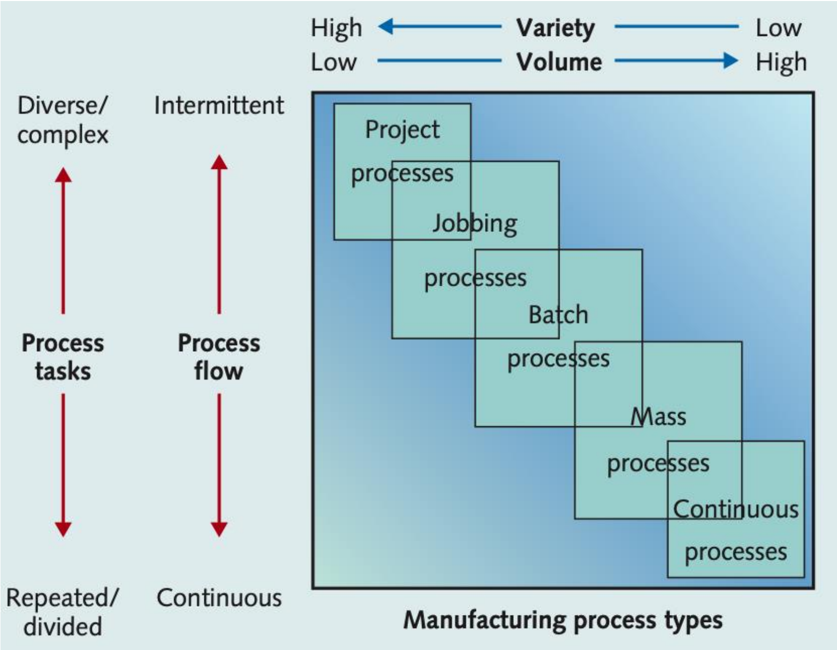


Figure 2.1 Different process types [17]

2.2 Layout types

Deciding which process type to use for a certain process is a strategical decision. Afterwards creating a suitable layout is necessary – a more tactical decision [8]. A layout is the physical arrangement of facilities relative to each other. It specifies where to place machinery and equipment, how materials will flow through the operation and how the general appearance is designed. Layout and look govern the efficiency, flexibility, safety and attractiveness of an operation [18]. The aim of layout is to reduce the cost of transportation and material handling, efficiently utilize space, equipment and workers, increase throughput, reduce lead times, improve product and process quality, improve employee morale and safer corking conditions etc. which result in higher profits [14]. Mainly 4 different layout types can be differentiated: [9], [15], [19]

- Fixed-position layout;
- Functional layout;
- Cell layout;
- Line/product layout.

Fixed-position layout is often called also static layout in literature. In this layout the product is stationary and does not move, however, all materials, machines, people and equipment are brought to the product. The reason for this could be that the products are too large or inconvenient to move [18]. Fixed-position layouts have an higher administrative cost than other layout types as coordinating workers and all timely deliveries of materials and equipment is time-consuming. Examples of an fixed-position layout are shipbuilding and large construction projects, e.g. skyscrapers and power plants.

Functional layouts are also named as process layouts or job shop process layouts. In this layout type similar resources and jobs are grouped together due to convenience or more efficient space utilization, e.g. milling machines are placed nearby and soldering stations in another area. It is often used for process that have a high degree of variety and relatively low volume, meaning that the equipment is flexible and can be used for different jobs. Different products need different operations, therefore, they flow through functional areas in unique routes. Since the equipment is placed by type not processing sequence, then the system is more robust and not so sensitive in case of different failures [9], [14]. For example, this kind layout is used in metal processing company which has a certain areas for welding, bending and painting.

A cellular or cell layout is a layout type where people and machines are working together to produce a certain product or family of products. The product moves in a predetermined flow through the cell. Therefore, the cell is a miniature version of product layout where product flow is smooth and transportation distance and material handling is minimal [18]. It tries to combine the flexibility of a functional layout with the efficiency of a product layout. Moreover, space utilization is improved [20]. For example, a cell layout is used in electronic components manufacturing where a product or product family has its cell.

Line layout is often also called product or flow layout. The equipment, machines and transport systems are located specially for a certain product which flow smoothly according to predefined route and sequence of activities. This type of layout is frequently associated with assembly lines. Due to standardized products and processes, also due to specialized workers and equipment, a rapid and predictable flow is achieved [9]. Labour and equipment utilization is high. Equipment used tends to be very capital intensive. On the other hand, not so expensive labour is needed. Products move directly from one operation to another, meaning the WIP is low. However, as the operations are tightly connected, the system is vulnerable to different failures [21]. As an example, line layout is used in assembly lines of car industry.

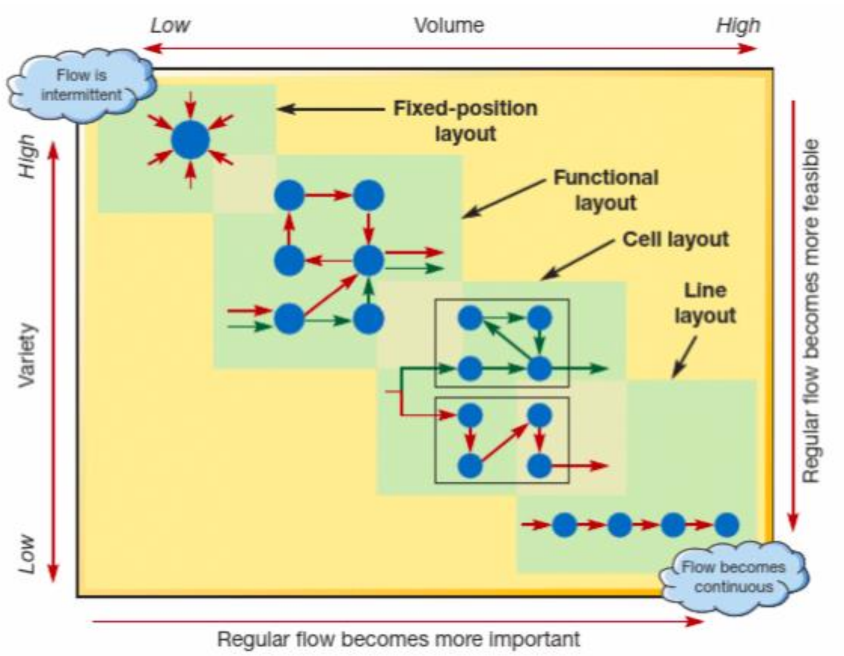


Figure 2.2 Different process layouts [9]

Besides using one of the four layout types, many operations use combinations of several layouts or use the basic layout types in different parts of the operation. This kind of layout is often named mixed, combined or hybrid layout. For example, the main assembly takes place in a product layout but sub-assemblies and other preparations are done in a cell or functional layout [9], [14].

2.3 Tools supporting layout efficiency

2.3.1 Standardization

Taiichi Ohno, one of the developers of Toyota Production System has said that there cannot be improvement if there are no standards [22]. A standardized process is the one where a method of performing a certain task is defined, successfully tested and repeatable [23]. All employees perform the task in the same way on every occasion. Standardized processes should be as efficient as possible and are more sustainable than non-standardized processes. By more sustainable it is meant that processes are well defined and documented and are not dependant on any individual or his/her knowledge [24]. The advantages of standardized processes are reduced wastes, lower unit costs, improved product quality, the same process output, accurate delivery dates etc. Moreover, the best practices are consolidated, increasing reliability and quality [16]. In addition to that, standardization helps to clarify processes, enhancing consistency and stability. As a result, it decreases labour turnover, employees are less stressed as the know how to act in different situation and it helps to onboard and train new employees more easily [25]. The standardized procedures, processes, guidelines and layouts are documented and displayed on posters, displays or other visual materials so it would be always in sight and reminded to the employees. Standardization is not a set of documents that is just needed to be followed and controlled, it is a way of creating the most consistence performance possible.

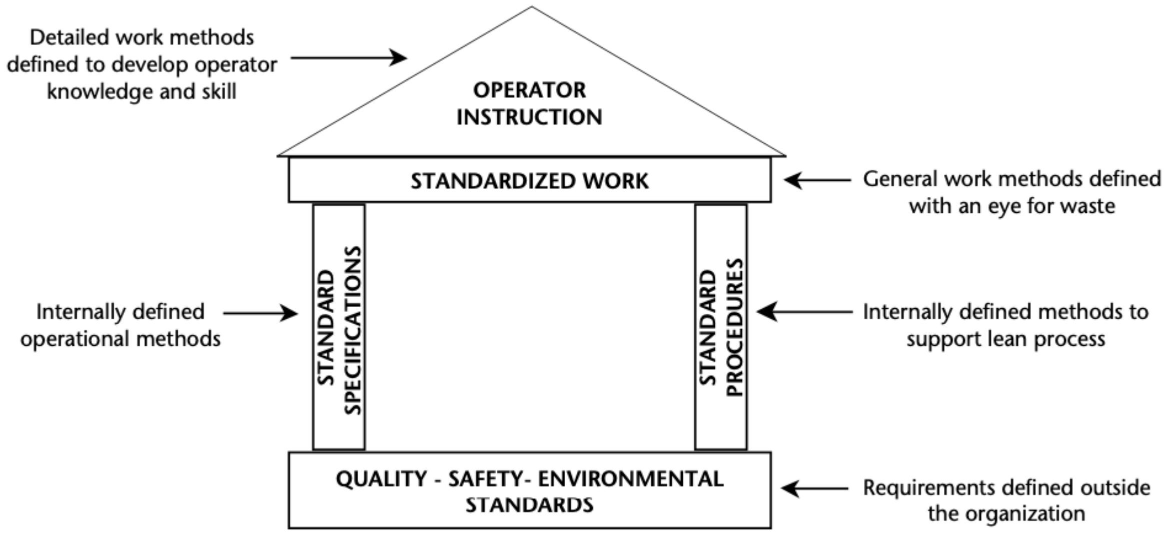


Figure 2.3 The relationship and aim of standards [26]

2.3.2 Visual Management

Visual management is management by sight. The work area is self-explaining, self-regulatory and self-improving. Visual management consists of 5S, visual displays and visual controls [27]. Visual control is a lean tool used to improve and standardize the work place and production. Instead of texts or other written instructions, information is communicated by using visual signals, for example signs, symbols and colours. In that way information is easily readable and understandable. Visual control helps to identify problems, reduce waste, create a safe working environment, help employees to stay up to date on current conditions etc. [28].

In production visibility helps to sustain workplace order meaning tools are easily available and abnormalities noticeable [20]. Due to visual workplace the employees need less supervision since they understand the standard and know how to act and what to do in certain situations [15]. The visual displays show the status of tasks, processes, projects, employees etc.

The aim of visual management and visual controls is to identify when something is out of standard. This could be noticed easily when looking at a certain area. There are many different forms for visual management. For example: [25]

- Shadow boards and labels that indicate if something is missing from its place;
- Painting, taping areas where a component, cart etc. should be located, color-coding component boxes, tools etc. for a certain product;
- Marking acceptable ranges to gauges, storage boxes, equipment to indicate if something is out of standard;
- Whiteboards to assign tasks to employees, display daily plans etc.

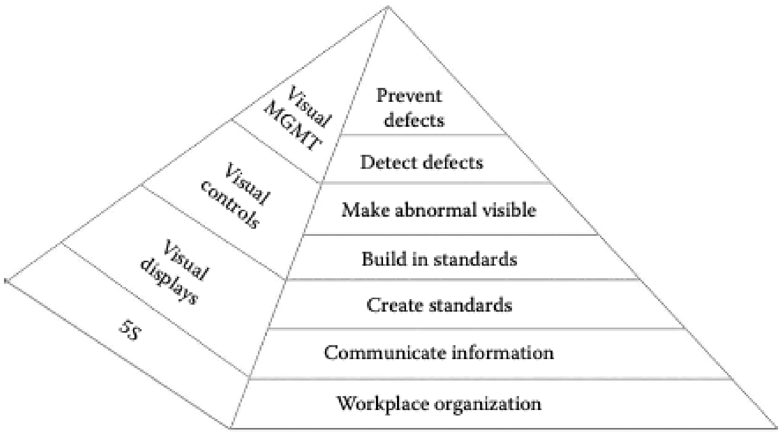


Figure 2.4 Visual management pyramid [27]

2.3.3 Ergonomics

Ergonomics is fitting the task to the employee in a work environment. It includes anatomy, physiology and psychology to design the jobs and work environment [21]. Ergonomics, also called human engineering, has two main objectives. Firstly, it tries to improve efficiency and effectiveness at a workstation by increasing convenience of tools use and motion. Secondly, it prevents fatigue. Ergonomics aims to provide comfortable and improved working conditions for the employees. As a result, productivity and safety are increased, labour turnover and job injuries are reduced [16]. Poor posture can lead to low productivity, fatigue and back, neck and arm injuries, which all could be avoided by designing workplaces where the posture is good. Ergonomics focuses on design and function of workstations, tools, displays, safety devices and lighting in order to ensure the health and well-being of workers by reducing stressors that cause repetitive motion injuries and fatigue. Nowadays most ergonomic problems are caused by more specialized production tasks, increased repetition, faster assembly lines and lack of ergonomically designed technologies [29].

Figure 2.5 Aspects of a comfortable and healthy workstation [14]

Motion study is the study of employees´ motions that are used in a job task. Its purpose is to remove all unnecessary motions and sequence motions in a way that a job is carried out as efficiently as possible. It is an effective way to design repetitive manufacturing operations. Motion study has 3 main aspects:

- efficient use of the human body – work should be simplified, rhythmic and symmetrical;
- efficient use of equipment – tools and equipment should enhance worker abilities, also should be constructed to fit worker use;
- efficient arrangement of the workplace – materials, components, tools, etc. should be placed as close as possible in order to minimise motions. The workplace should be comfortable and healthy [30].

2.3.4 Key performance indicator

Measuring operational performance is an important part of every organization. Key performance indicator is a quantitative value that is used for performance evaluating and which also helps to coordinate and guide different business units to achieve the overall organization goals. Having set KPI-s, the organization indicates how it expects its employees to behave and how it is measured. Key performance indicators vary depending on the nature of the company. They are measured daily, however, the results are analysed less frequently, e.g. on a weekly, monthly or yearly basis. When designing KPI-s it is important not to implement too many of them, otherwise, the focus will fade. Moreover, all necessary factors need to be included in the design to achieve measurable results and concentrate on the ones that help the organization to achieve its goals [24]. It is important that the KPI-s are concrete and base on the SMART model, meaning the indicators are specific, measurable, achievable, realistic and timely. In order to measure the performance of a production layout, there are several different KPI-s that could be used, for example, product flow distance, layout area size and throughput.

3 CURRENT LAYOUT ANALYSIS

As mentioned earlier, the current production layout can be categorized as a functional layout. Operations are carried out in workstations that have the necessary equipment and tools. For example, testing and programming the PCB-s is taking place at tables with computers. The production is carried out in batches. As the space is limited, then there are not fully standardized workstations for every operation. Certain tasks, e.g. enclosure preparation, are done at a table that is currently vacant which may cause unnecessary transportation of parts and subassemblies from one place to another and time looking for a specific tool or parts.

The current production premises can be divided into 3 sections – production area, packing area and storage room. In total the size of the production premises is approximately 137,3 m^2. Taken into consideration that production team currently shares the rooms with hardware development and support team then the real area used for production operations is approximately 106,1 m^2. The sizes of each production premises section are displayed in Table 3.1

Table 3.1 Sizes of production areas (As Is)

No.	Area	Size (m^2)	Area for production operations (m^2)
1	Production	68,9	56,1
2	Packing	20,0	20,0
3	Storage room	48,4	30,0
	TOTAL:	**137,3**	**106,1**

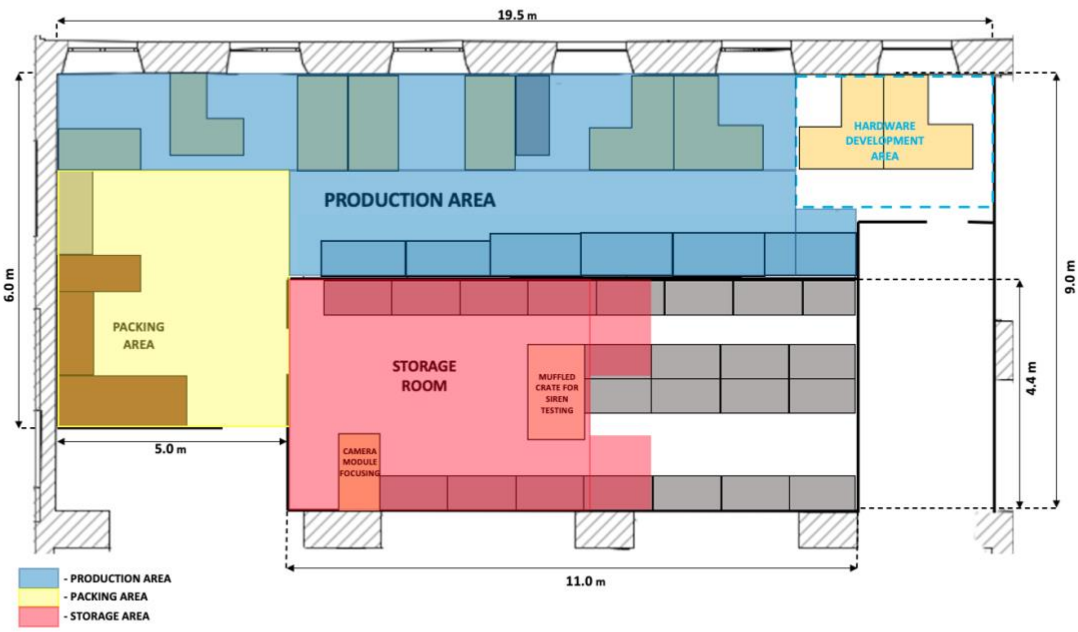


Figure 3.1 Sections of production premises

In the production area all tests and assemblies are carried out together with maintenance and repair works. All incoming and outcoming goods move through the packing area. Here all customer orders are put together, packed and labelled according to transportation requirements. Additionally the packages are folded and prepared in the packing area. Moreover, incoming components are also temporary stored in the packing area until they have been inserted into the ERP system and moved to the storage room. All components, packing materials etc. are stored in the storage room. In addition, here camera modules are being focused at a special workstation and sirens tested inside a custom-made muffled crate. Approximately a bit more than half of the storage room is for production-related goods. In the other half, the goods and equipment of development, support and marketing are stored.

Figure 3.2 Packing area (As Is)

3.1 Detector production layout analysis (As Is)

The detector is a product with the highest production volume and longest production time. It takes 15 different process steps to manufacture a detector. The process steps and average process times are listed in Table 3.2. Due to confidentiality the process times have been modified and multiplied by a certain coefficient, therefore, the time needed to manufacture 1 detector is set to 1 hour. The time of packing the detector is currently not included into the manufacturing time as it is too dependent on what extra equipment is ordered with the devices.

Table 3.2 Durations of detector production steps

Activity	Average time (sec)
PIR module testing	234
Radio module testing & programming	193
Radio module configuration & cert loading	349
Camera module - adding lenses	297
Camera module focusing	350
IR Flash module testing	85
Enclosure A preparation	39
Enclosure A assembly	354
Enclosure B preparation	39
Enclosure B assembly	380
Enclosure B stacking	347
Production in ERP	516
Final test & assembly	282
Folding carton package	135
Packing	-
Total: 15 activites	**Total: 3600 sec**

The precedence diagram of the detector's production process is in Figure 3.3 where the sequence of operations is visualized.

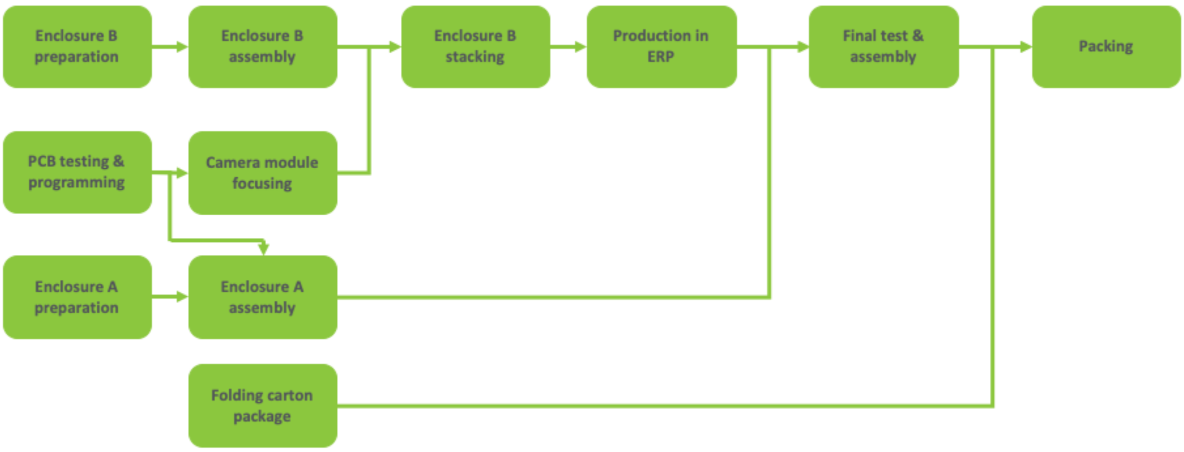


Figure 3.3 Precedence diagram of detector production process

It is possible to concurrently test and program the PCB-s, prepare and assemble the first and back enclosures and fold the carton package. The detector has four different electronic modules which can be tested simultaneously with special testers. Additionally, the camera module needs lenses to be screwed on and focusing which is done behind a single-purpose banner in the storage room. The reason why the focusing is done in the storage room is due to the constant lightning conditions as there are no windows. Camera module focusing against the single-purpose banner is displayed in Figure 3.4.

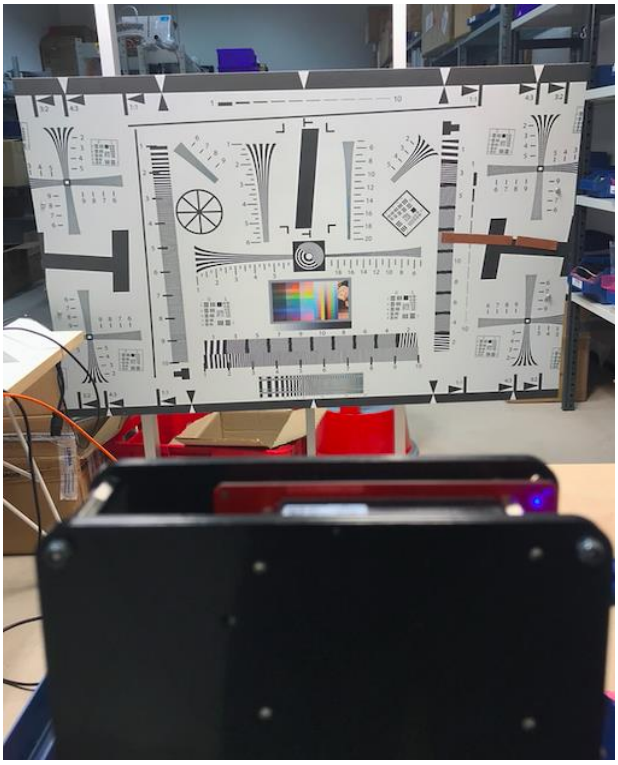


Figure 3.4 Camera module focusing against a single-purpose banner

The enclosure preparation means clipping off a piece of the enclosure and strengthening the inserts of the enclosure with glue. This process could be left out from the production if a solution is found for the enclosure mold. During first and back enclosure assembly all needed parts are added to the enclosure, e.g. PIR lenses and fastening units. Then the back enclosures move on to the stacking process which means that tested electronic modules are assembled into the enclosure like a constructor with bolts, spacers and cables. The stacked detectors are registered in the ERP system which means filling in all the necessary information regarding a specific device – its serial number, ID, configuration and customer information. During this process it is already validated whether the device is connecting via the radio frequency and sending photos. Then the final assembly and testing takes place. These are basically done simultaneously – if one detector is being tested then another detector is already being assembled together for the final test. During the final test it is confirmed that all the functionalities work properly, therefore, it is also a quality control. If the final test is successful then the detectors are moved into the packing area where they are packed according to the customer's order. Most of the products are packed into carton packages that are previously folded but another possibility is packing into as waterproof case that has a custom foam inside.

As previously mentioned then many assembly operations are carried out at a table that is currently vacant since the functional production layout is also used for siren and bridge production. The author has identified workstations by observation where the certain activities take place in most of the time. In Table 3.3 it is shown how the product and its subassemblies move between operations with their distances. In total, the detector and its subassemblies currently move 77,0 meters around the premises during the production process. The product flow of detector is visualized in Figure 3.5. As seen, the flow is quite intermittent and paths are often crossing between workstations.

Table 3.3 Product flow distances of a detector production process (As Is)

Operation marking	Activity	Movement between operations	Distance (m)
A	PIR module testing	A → H	6,0
B	Radio module testing & programming	B → C	0,5
C	Radio module configuration & cert loading	C → K	0,5
D	Camera module - adding lenses	D → E	9,5
E	Camera module focusing	E → K	15,0
F	IR Flash module testing	F → K	5,0
G	Enclosure A preparation	G → H	13,0
H	Enclosure A assembly	H → M	9,5
I	Enclosure B preparation	I → J	1,5
J	Enclosure B assembly	J → K	1,5
K	Enclosure B stacking	K → L	0,5
L	Production in ERP	L → M	0,5
M	Final test & assembly	M → O	13,0
N	Folding carton package	N → O	1,0
O	Packing	-	-
	Total: 15 activites		**77,0**

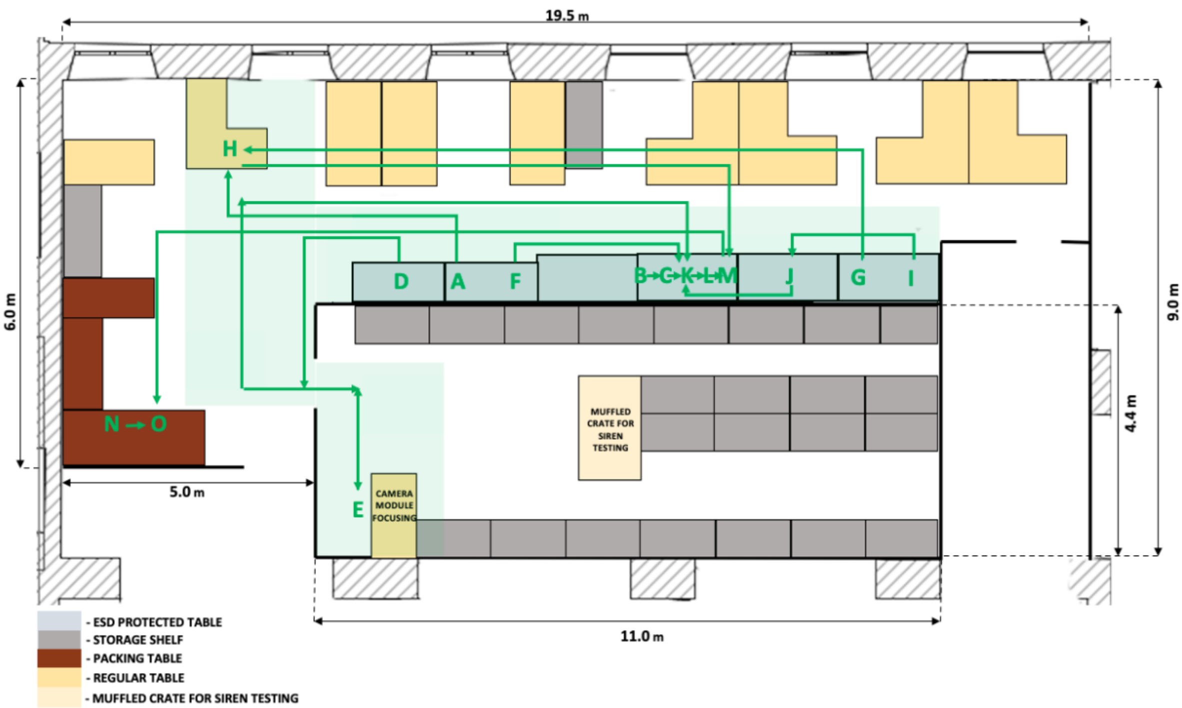


Figure 3.5 Detector flow during production (As Is)

Figure 3.5 also indicates the layout area used for detector production in green colour. It covers the workstations used during the production process including the paths from workstation to another. It total, the area size of detector production layout is approximately 43,2 m^2. For simplicity, the areas for folding the carton package and packing are excluded as these activities are done separately at a packing area. Similarly, the packing workstations are also cross-used with folding carton packages for sirens and bridges and the packing area will be a completely separate room in the new production premises on the first floor.

In each workstation there are certain components needed for carrying out the production operation. Before starting the operation, the necessary components are brought from the storage room with carts in one time. At first, the components are picked from the storage section which is the farthest away and the worker then moves towards the workstation with the cart and picks other components that are needed for the operation from closer storage sections. Table 3.4 displays the components used in each workstation, storage section where the components are taken from and the distance covered by the single pick-up from the storage room to the workstation. Some workstations, e.g. camera module focusing (operation marking E) do not need components from the storage room as they just need input from the previous workstation. In total, 12 different component pick-ups are done during the production process, covering approximately 145,0 meters.

Table 3.4 Movement of detector components (As Is)

Pick-up No	Movement to operation	Storage section marking	Components	Distance (m)
1	A	2.0	Untested PCB-s	1,5
2	B & C	2.0	Untested PCB-s	5,5
3	D	2.0	Untested PCB-s	10,0
		2.6	Lenses	
4	F	2.0	Untested PCB-s	1,5
5	G	2.4	Enclosures	19,5
6	H	2.4	Enclosures	18,5
		2.5	Cables, seals	
		2.7	Tested PCB-s	
		2.8	Metal (nuts & bolts)	
7	I	2.4	Enclosures	19,5
8	J	2.5	Cables, seals	19,0
		2.8	Metal (nuts & bolts)	
9	K	2.7	Tested PCB-s	17,5
		2.8	Metal (nuts & bolts)	
10	M	2.5	Cables, seals	17,5
		2.8	Metal (nuts & bolts)	
11	N	2.3	Packing material	9,0
12	O	2.1	Extra equipment	6,0
			TOTAL:	**145,0**

The movement of detector components from the storage sections to workstations are visualized in Figure 3.6. The thicker the movement line is on the figure, the more times this path is being travelled. One storage section, point 2.0, is outside the storage room. This is a table where all untested PCB-s are stored until they are tested. In that way the untested PCB-s are always in sight and if there should be idle time for some workers then they can continue with the testing. If the tests are successful, then PCB-s are marked with a green label and moved to the storage room. If not, then the PCB-s are marked with a red label and put aside for further inspection.

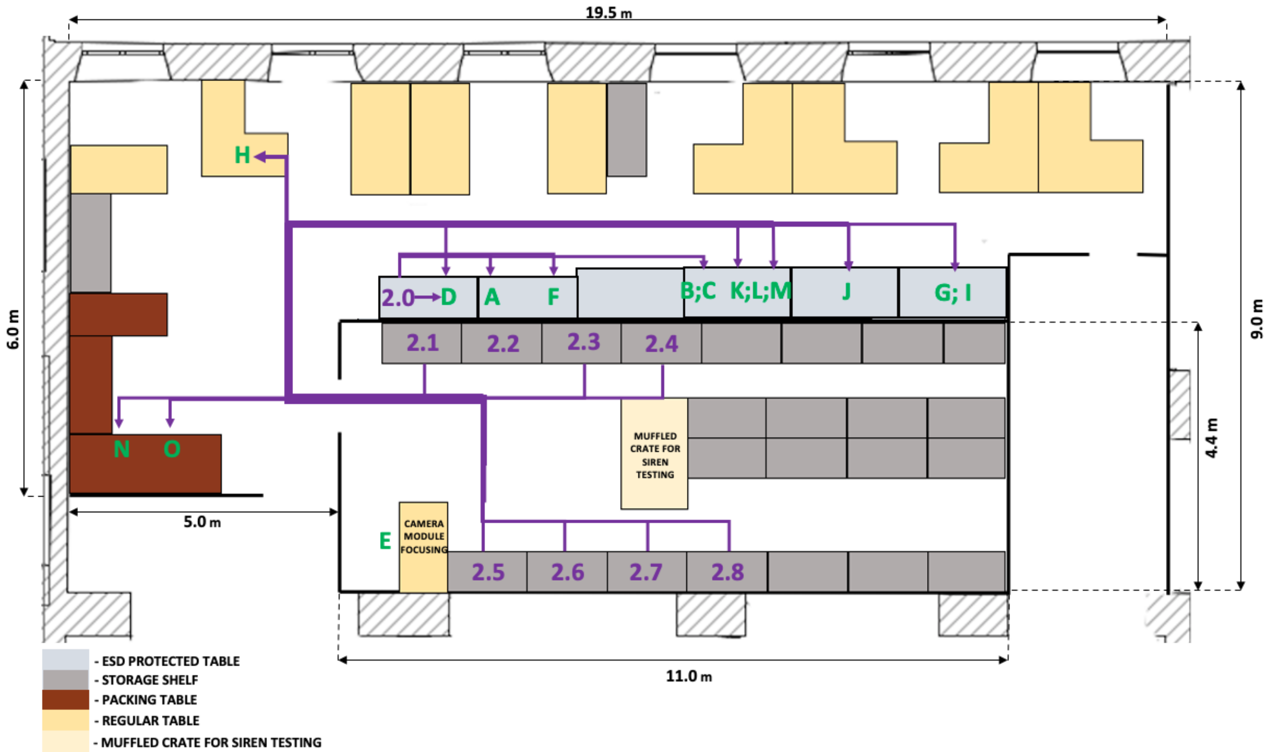


Figure 3.6 Movement of detector components (As Is)

3.1.1 Detector production process simulation (As Is)

Since the detector production volumes are the highest, only a simulation of the detector production process is carried out for comparison purposes how a layout change and reducing product flow distance can affect the productivity. In the current chapter, results of the as-is production process is presented. The simulation is carried out with Siemens Tecnomatix Plant Simulation software. It allows to model, simulate, visualize and optimize different production and logistics processes [31]. Author decided to use the Tecnomatix Plant Simulation among its alternatives Arena and Visual Components due to its functionality and the previous experience of using it. The As Is simulation model is displayed in appendix 1.

As mentioned, the aim of the simulation was to find out how a well-designed production layout with reduced product flow distances can affect the production productivity. The production process of detector was modelled in the software including the all the production steps except folding carton package and packing the device. These activities are carried out in the packing area. The simulation included the real durations of operations and distances between workplaces until the packing area. The product movement speed between operations was set to 0,8 m/s which is estimated to be the speed of that a worker moves when carrying parts. Since the workplaces are cross-used with bridge and siren production activities in reality then a setup time of 3-5 minutes was added to each operation depending on its peculiarities. This would include looking for necessary tools, components, testers and etc. to the workplace. It is important to note that for simplification the simulation was carried out as if every workplace would be manned. This would display the results of reducing the product movement distances most clearly. Based on the conditions mentioned above, the outcome of the simulation is that the daily throughput of the detector production process during an 8-hour working day is 54 detectors.

The utilization of different workplaces in the simulation are displayed in Figure 3.7. As expected, the utilization of workplaces is not efficient and they are out of balance. The simulation shows that the bottleneck of the process is registering the detector into the ERP system with all necessary information. In reality, each workplace is not manned and workers perform operations in batches and move between different production activities as needed. Line balancing is a separate topic that is not being analysed in the current master thesis.

Operation Marking	Production operation	Utilization (%)
A	PIR module testing	43.6%
B	Radio module testing & programming	36.0%
C	Radio module configuration & cert loading	65.1%
D	Camera module - adding lenses	55.4%
E	Camera module focusing	65.2%
F	IR Flash module testing	15.8%
G	Enclosure A preparation	7.3%
H	Enclosure A assembly	66.0%
I	Enclosure B preparation	7.3%
J	Enclosure B assembly	70.8%
K	Enclosure B stacking	64.7%
L	Production in ERP	96.2%
M	Final test & assembly	52.3%

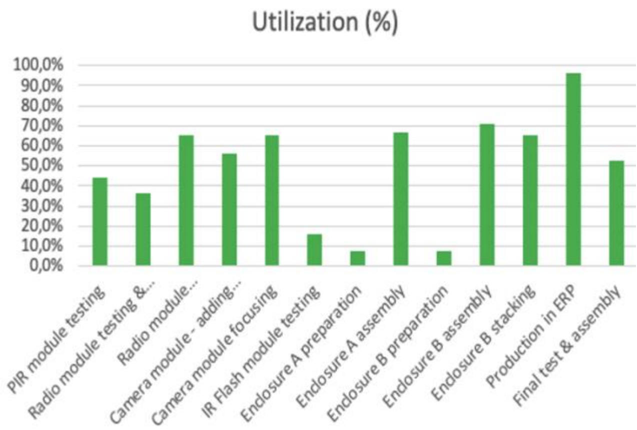


Figure 3.7 Utilization of workplaces (As Is)

3.2 Bridge production layout analysis (As Is)

The production process of the bridge has the shortest cycle time and it consists of the fewest components. Bridge manufacturing consists of 9 process steps. These are listed in Table 3.5 with durations. The durations are again multiplied with the same coefficient as detector production steps due to confidentiality. The total time needed for bridge manufacturing is approximately 40 minutes. The time of packing is also not included into the manufacturing time as it is too dependent on what extra equipment is ordered with the devices.

Table 3.5 Durations of bridge production steps

Activity	**Average time (sec)**
PCB testing & programming in tester 1	573
PCB testing & programming in tester 2	550
Enclosure A preparation	316
Enclosure B preparation	77
Enclosure A stacking	0
Production in ERP	388
Final assembly	0
Folding carton package	477
Packing	-
Total: 9 activites	**Total 2381 sec**

The precedence diagram of the bridge production process is in Figure 3.8 where the sequence of operations is visualized.

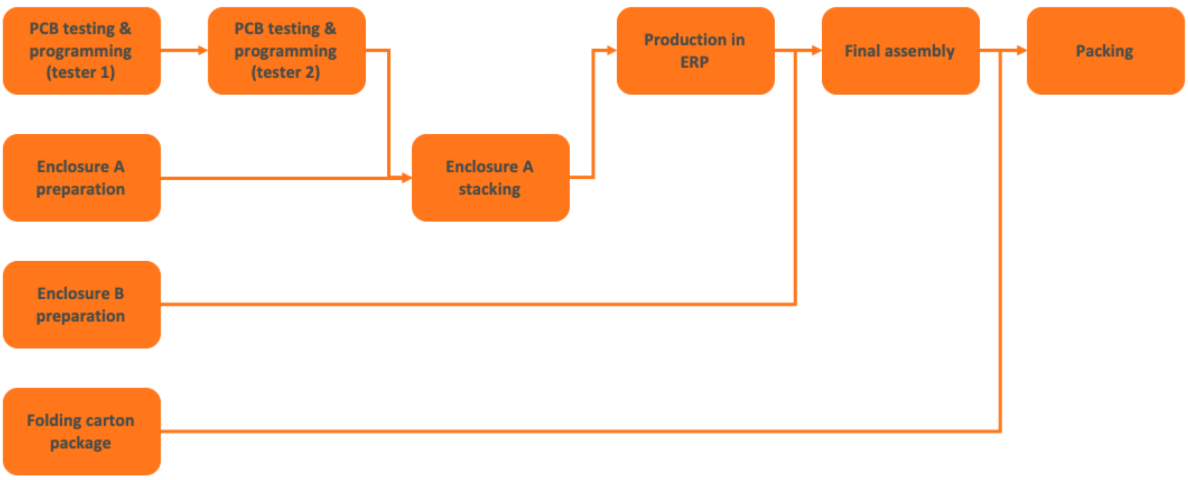


Figure 3.8 Precedence diagram of bridge production process

The bridge only has 1 electronic module inside which performs several functions. Therefore, two different testers, which are located in separate workstations due to technical reasons, are needed for testing these functions, program the PCB and load the security certificate. Simultaneously, it is possible to prepare the first and back enclosure of the bridge and fold the carton package for it. If the first enclosures are already prepared before the PCB testing in and programming in tester number 2 then it is possible to merge these to activities together. If one PCB has been tested and programmed then it can already be stacked into the enclosure while another PCB is being tested. This is the reason why the enclosure A stacking duration has been marked as 0 seconds in Table 3.5. Then the bridge is produced in the ERP system meaning that all the information of the stacked bridge is filled in into the ERP – its serial number, ID number, customer information, configuration etc. Device functionality is also verified during this process step. Once this has been done, the bridge moves on to the final assembly. This operation can also be together with the previous operation – production in ERP. If the necessary information regarding one bridge is filled into ERP system, it can be assembled together while another bridge connects to production tools in order to produce it in the ERP. Therefore, the process duration is also set to 0 seconds for final assembly in Table 3.5. Assembled devices are moved to the packing area for packing.

Table 3.6 displays the movement of the product and its subassemblies between operations and the distance covered. In total, the distance covered during production process is approximately 28,5 meters. The movement between operations is visualized in Figure 3.9. It also indicates the layout area used for bridge production in light red colour. In total, the area size of bridge production layout is approximately 25,4 m^2. For simplicity, the areas for folding the carton package and packing are excluded from the layout area size for the same reason as in the case of detector layout.

Table 3.6 Product flow distances of a bridge production process (As Is)

Operation marking	**Activity**	**Movement between operations**	**Distance (m)**
A	PCB testing & programming in tester 1	A → B	7,0
B	PCB testing & programming in tester 2	B → E	0,5
C	Enclosure A preparation	C → E	8,0
D	Enclosure B preparation	D → G	0,5
E	Enclosure A stacking	E → F	0,5
F	Production in ERP	F → G	1,5
G	Final assembly	G → I	9,0
H	Folding carton package	H → I	1,5
I	Packing	-	-
	Total: 9 activites		**28,5**

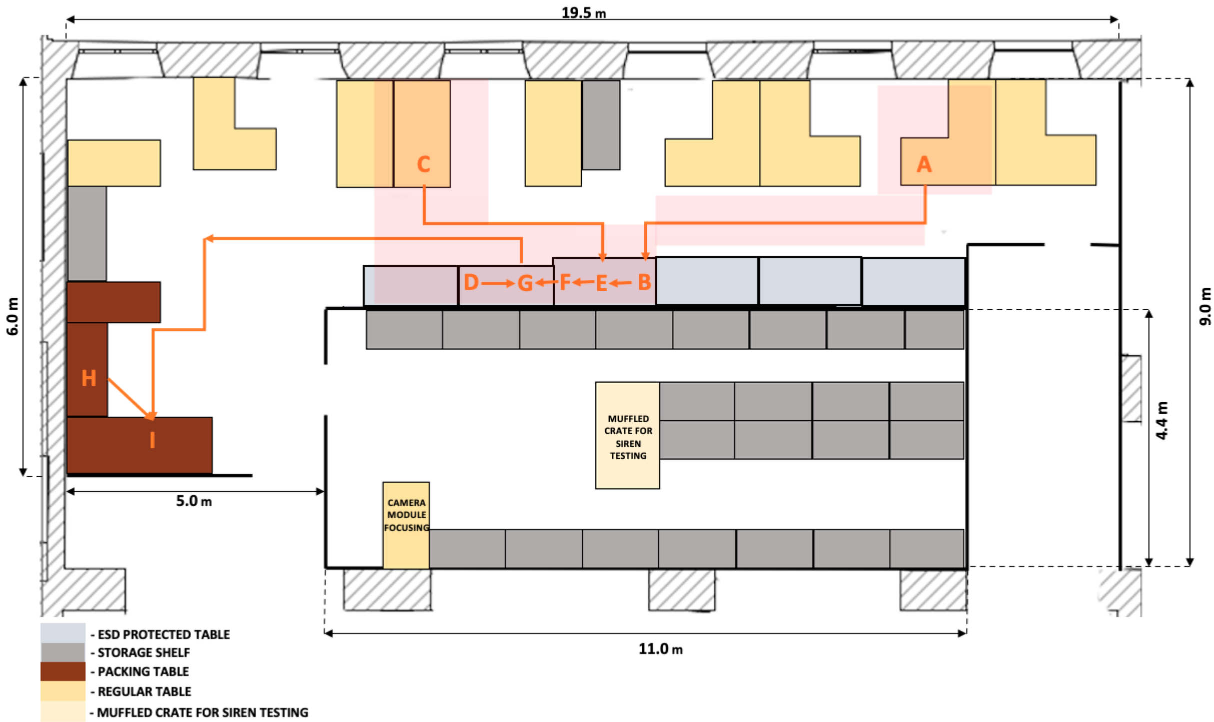


Figure 3.9 Bridge flow during production (As Is)

7 operations from the bridge production process need components from the storage room. These operations and component movements are displayed in Table 3.7 together with the movement distances. Each component pick-up has the same logic – at first, the components are picked from the storage section which is the farthest away from the storage room entrance and then the worker is moving towards the workstation with a cart and picking other necessary components on the way. In total, the distance covered from the storage sections to workstations during the 7 pick-ups is approximately 88,5 meters.

Table 3.7 Movement of bridge components (As Is)

Pick-up no	**Movement to operation**	**Storage section marking**	**Components**	**Distance (m)**
1	A	2.0	Untested PCB-s	8,5
2	C	2.4	Enclosures	17,0
		2.5	Cables, seals	
3	D	2.4	Enclosures	18,0
		2.8	Metal (nuts & bolts)	
4	E	2.8	Metal (nuts & bolts)	16,0
5	G	2.5	Cables, seals	14,0
		2.8	Metal (nuts & bolts)	
6	H	2.3	Packing material	9,0
7	I	2.1	Extra equipment	6,0
			TOTAL:	**88,5**

The component pick-ups are visualized in Figure 3.10. The thicker the movement path is, the more time this path is being travelled. Again, storage section 2.0 is for storing the untested PCB-s until they are tested.

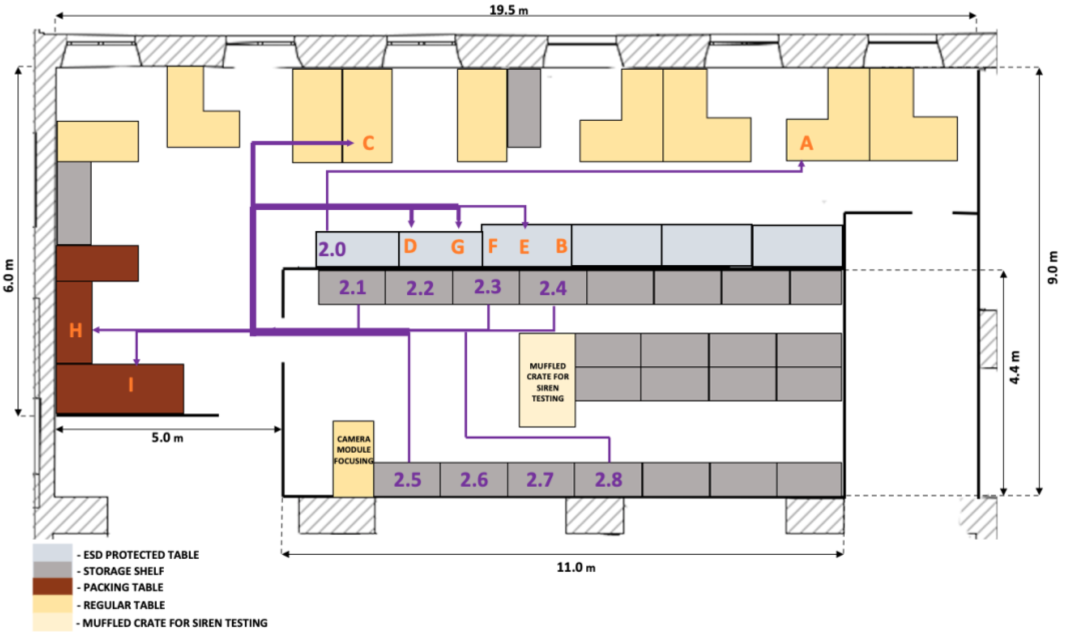


Figure 3.10 Movement of bridge components (As Is)

3.3 Siren production layout analysis (As Is)

Siren manufacturing includes 11 different operations. These operations are listed in Table 3.8 together with their timings. Due to confidentiality the process durations are multiplied with the same coefficient as the process durations of detectors and bridges. As a result, the time needed to manufacture a siren is approximately 57 minutes. This does not include the packing time as it is dependent on what extra equipment is ordered with the devices.

Table 3.8 Durations of siren production steps

Activity	Average time (sec)
Connecting PCB 1 with beacon	205
Testing PCB 1 & beacon	282
PCB 2 testing, programming	193
PCB 2 cert loading	282
Enclosure A preparation	740
Enclosure B preparation	77
Enclosure A stacking	429
Production in ERP	539
Final assembly	154
Folding carton package	539
Packing	-
Total: 11 activites	**Total: 3440 sec**

The precedence diagram of the siren production process is in Figure 3.11 where the sequence of operations is visualized.

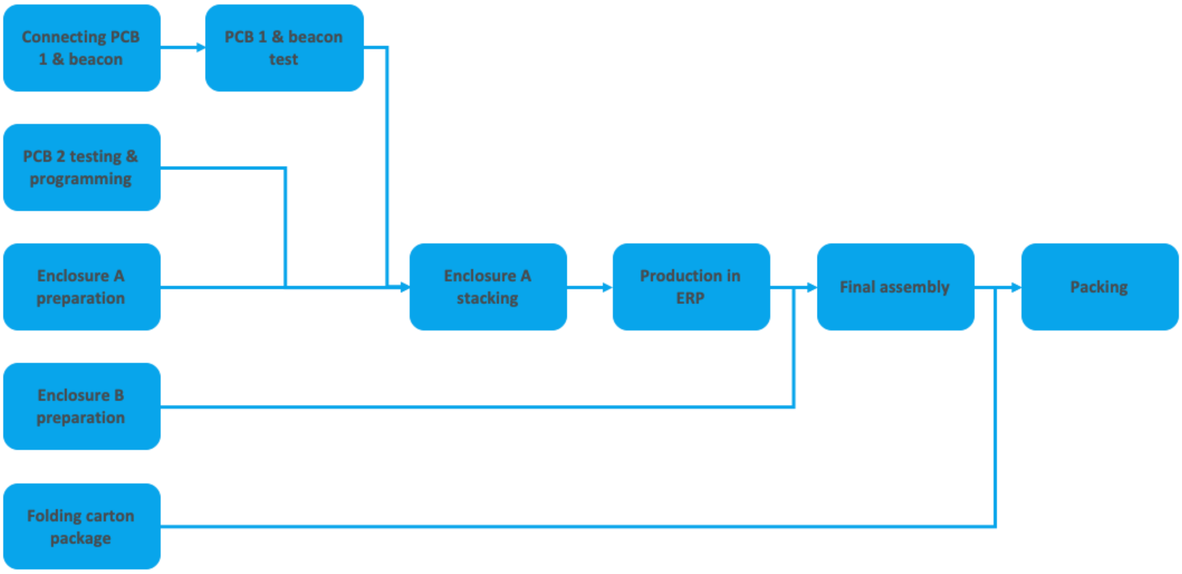


Figure 3.11 Precedence diagram of siren production process

The enclosure of the siren is based on the bridge enclosure which is a bit modified. There are 2 different electronic modules inside the siren which can be tested concurrently along with first and back enclosure preparation and folding a carton package. One of the PCB-s is tested, programmed and certificate loaded in a tester connected to the computer, the other PCB is connected to a beacon by manually screwing wires into PCB and beacon connectors. Then both the PCB and the beacon can be tested. The test is carried out in the storage room inside a special muffled crate as the siren can generate over 90 dBm loud alarm. The muffled crate is located in the storage room to reduce the noise level in the production area.


Figure 3.12 Muffled crate for siren testing

If the electronic modules are tested and enclosures are prepared, the stacking of the siren can begin which means that tested electronic modules are assembled into the enclosure like a constructor with bolts, spacers and cables. The stacked siren is then produced in the ERP system where all necessary information – e.g. serial number, ID number, configuration and customer information - is filled in regarding a certain device and it is tested that the siren is working properly. During the device production in ERP the siren is physically put into the muffled siren testing crate and the siren is activated for an alarm. After that the first enclosure and back enclosure are assembled together, visual quality control is carried out and the siren is ready for packing.

Since the siren is physically similar to the bridge then the siren production is also carried out in basically the same workstations. Movement between workstations where the siren production operations take place in most cases is displayed in Table 3.9 together with the movement distances of the product and its subassemblies. The total product movement in the production premises is 52,5 meters. The product flow of a siren is visualized in Figure 3.13 which also displays the production layout area used for siren manufacturing in light blue colour. In total the layout area size is approximately 31.6 m^2 and it includes both the workstations and the movement paths between them. Similarly with the production layout of detector and bridge, the areas for folding a carton package for the siren and packing it are excluded from the calculated area size for simplicity.

Table 3.9 Product flow distances of a siren production process (As Is)

Operation marking	**Activity**	**Movement between operations**	**Distance (m)**
A	Connecting PCB 1 with beacon	A → B	11,5
B	Testing PCB 1 & beacon	B → E	11,5
C	PCB 2 testing, programming	C → D	0,5
D	PCB 2 cert loading	D → G	9,0
E	Enclosure A preparation	E → G	0,5
F	Enclosure B preparation	F → I	0,5
G	Enclosure A stacking	G → H	8,0
H	Production in ERP	H → I	0,5
I	Final assembly	I → K	9,0
J	Folding carton package	J → K	1,5
K	Packing	-	-
	Total: 11 activites		**52,5**

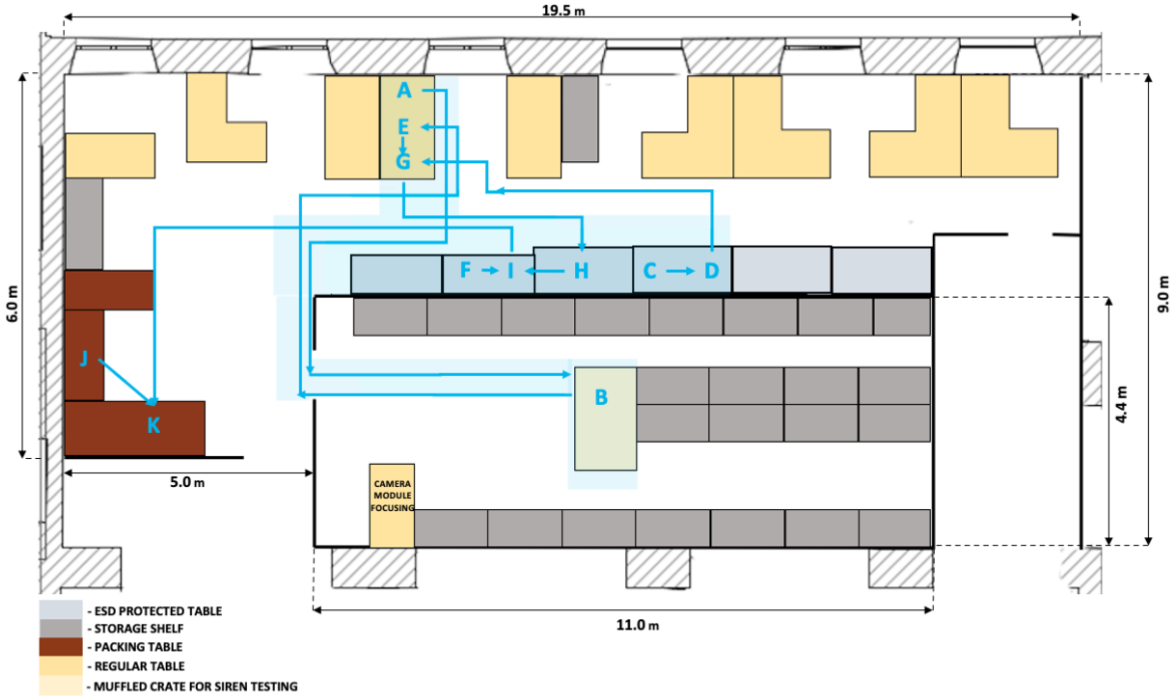


Figure 3.13 Siren flow during production (As Is)

8 different production operations need certain components from the storage sections. Table 3.10 displays the component movements from storage sections to workstations. In sum, the distance covered by the 8 component pick-ups is approximately 88,5 meters. The pick-up principle is the same – firstly components are picked from the storage section the farthest away from the storage room entrance and other components are added to the cart along the way to the workstation.

Table 3.10 Movement of siren components (As Is)

Pick-up no	Movement to operation	Storage section marking	Components	Distance (m)
1	A	2.0	Untested PCB-s	2,0
2	C & D	2.0	Untested PCB-s	5,5
3	E	2.4	Enclosures	21,0
		2.5	Cables, seals	
		2.8	Metal (nuts & bolts)	
4	F	2.4	Enclosures	18,0
		2.8	Metal (nuts & bolts)	
5	G	2.8	Metal (nuts & bolts)	13,0
6	I	2.5	Cables, seals	14,0
		2.8	Metal (nuts & bolts)	
7	J	2.3	Packing material	9,0
8	K	2.1	Extra equipment	6,0
			TOTAL:	**88,5**

The component pick-ups are visualized in Figure 3.14. The thicker the movement path is, the more time this path is being travelled.

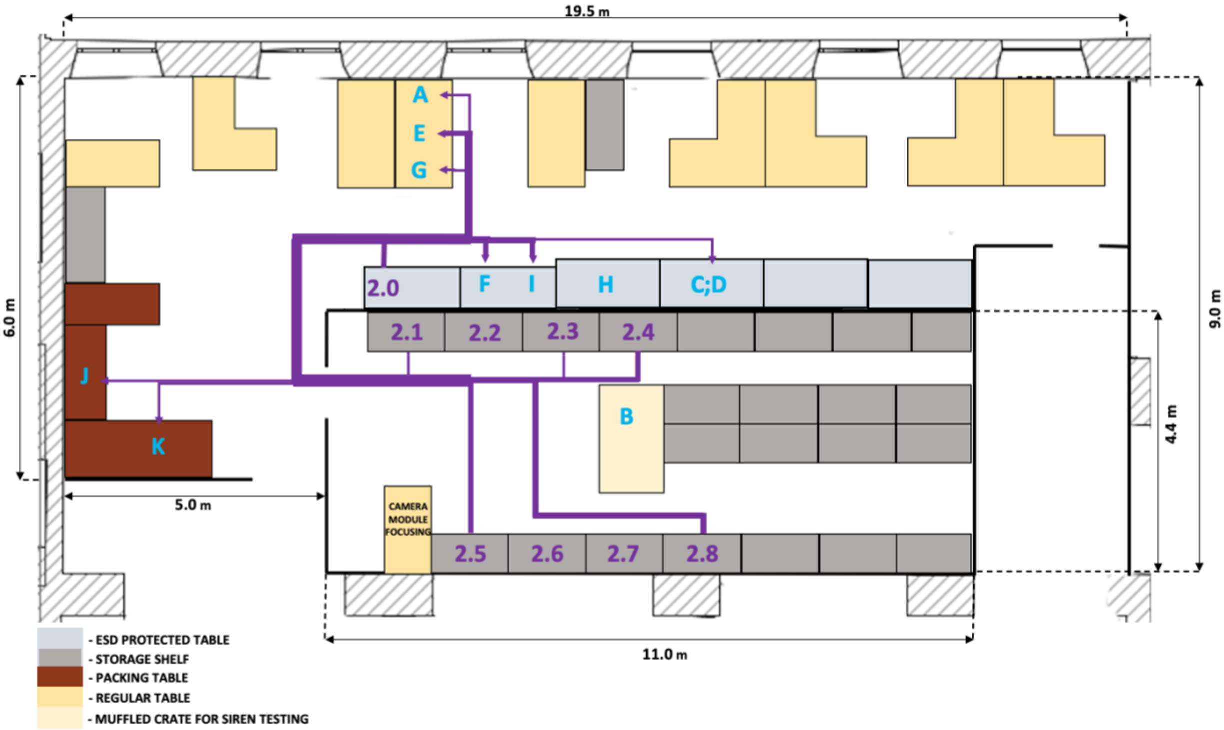


Figure 3.14 Movement of siren components (As Is)

4 PRODUCTION LAYOUT DESIGN AND STANDARDIZATION

The new production premises which Defendec will rent, are located in the same building and staircase section on Erika 14, Tallinn. The new premises will be used in addition to the current ones. However, the not all of the current production area will stay for production operations. After the production department will mainly move to the new premises, the freed up space will be taken over by the hardware development and support teams which are also expanding. The size of the new production premises is approximately 135,5 m^2 and it consists of three rooms, which are divided into the main production room (71,3 m^2), packing area (34,2 m^2) and production office room (29,0 m^2). The layout of the new production premises is displayed in Figure 4.1. As seen, there is not a separate storage room downstairs. The goods and components that are necessary for everyday standard production are stored in the production room and packing area which reduces the movement distance of components.

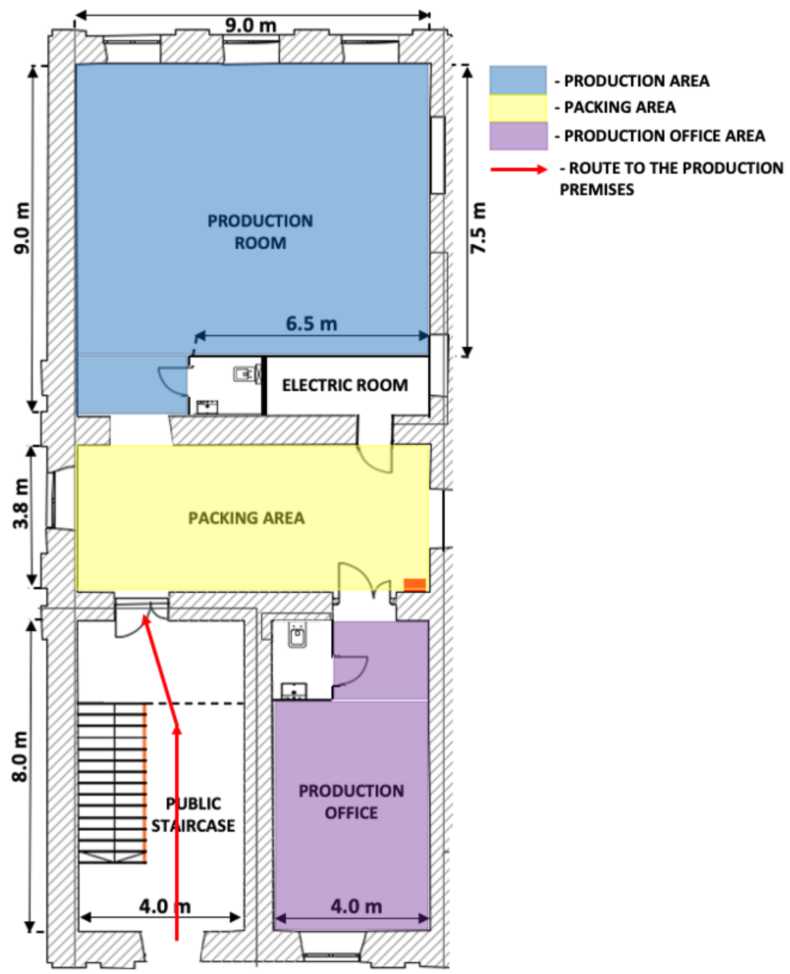


Figure 4.1 Production premises on the first floor (To Be)

The route length from the front door to the production premises will decrease drastically from approximately 40 meters to 8 meters. Moreover, there is no need to carry components and packed goods up and down the stairs which is 20 meters long. It is important to mention that production operations will take place both downstairs and upstairs. The activities carried out on the new premises are enclosure preparation, assembly, production in ERP, final tests and packing. These are the main operations for the standard products – detectors, bridges and sirens. Activities that will be carried out upstairs in the current premises are PCB testing and programming together with repair and maintenance of returned devices and production of lower-volume goods. The reason for testing and programming the PCB-s upstairs is that the testers can be connected to a certain workstation and there would be no set up time. The PCB-s that fail the tests can be put aside and investigated further for the fault detection by the engineers. Also repairing and carrying out maintenance for returned devices often need the PCB-s to be tested to ensure all functionalities are working properly and these devices also need final tests which will not affect the main production anymore. The movement up and down the stairs will remain but in much reduced quantity – the components are mainly stored downstairs. Also the tested PCB-s can be collected in hundreds in one pick-up which can be done once in the morning or during lunch break.

During the layout design process for the new production premises, a layout drawing of reduced scale was made onto the whiteboard and the equipment (tables, storage shelves, etc.) was cut out of a paper. Then the equipment was fixed onto the whiteboard with magnets and different layout options were tried to find the best result. As Nicolas [32] proposed the production workers were also involved into the new layout design process as they often are more aware of the size, shape and other features of the equipment than the managers. However, layout drawings do not give the full picture about the layout and the movement paths inside it. Therefore, once the equipment is physically in place then necessary adjustments can be made. The aim of the layout design is to enhance the efficiency of the production processes, increase capacity, provide visual control of activities, minimize the travel distances of employees, products and material and ensure the safety and satisfaction of the workers [16], [21].

Other environmental and production premises physical aspects were taken into consideration for the new layout design, for example lighting requirements, entrance location, noise level etc. As a result, a layout for the production room and packing area was designed which is displayed in Figure 4.2. It was designed in a way that all 3 main devices – detectors, bridges and sirens would have their own product layout for assembly. The main advantages of product layouts are established routing of products and materials, lower material handling costs, higher output rate, standardization and labour specialization etc. [14].

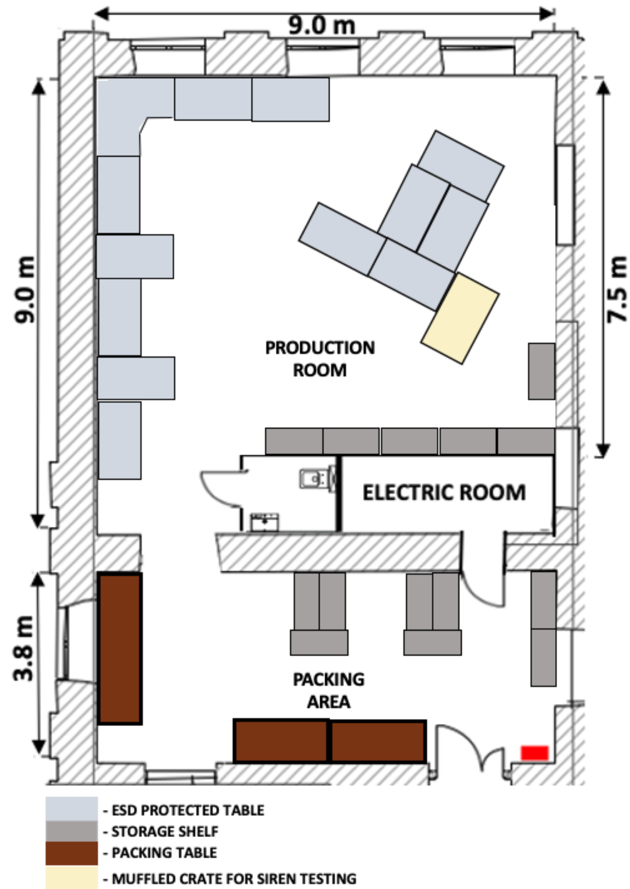


Figure 4.2 Production layout on the first floor (To Be)

The layout design was started by analysing the requirements for the production equipment, e.g. the number of tables, storage shelves, suction ventilation etc. At first, the position for the suction ventilation device was selected for the upper left corner in Figure 4.2. The aim was to put it into the corner of the room to maintain flexibility in case of future layout adjustments are needed. In that case suction ventilation device would not be in the middle of the room and limit a layout design. Also the initial plan was to place the workstations all near the windows but as there windows are there quite high from the floor (approximately 1,6 meters) then the daylight would not reach to the tables that are directly below the windows – they would be in the shadow. Instead of that the tables and workstations are placed in a way that the products would move towards the exit and packing area during the production process which will be explained in the further sections of this thesis. Also, some extra lighting will be put for the workstations. As mentioned previously then there will not be a separate storage room downstairs. The goods and components are stored near the area they will be used meaning that components used in production are stored in the production room and packing material with accessories and extra equipment are stored in the packing area. This would reduce the distance of component movement. The storage sections are put to the opposite wall from the windows as the workstations have been tried to locate closer to the windows. The storage room upstairs would still be used for storing components and goods that are for previous device versions and components that are used in repair and maintenance. Similarly, components that are not used in daily production are stored in the storage room. If currently the employees that manage the production are working in the production area then in the now layout they would have a separate room that is quiet and where it is possible to focus. Additionally, the production office room is a place where the production workers can keep their belonging etc.

As said, the current production area upstairs will be used for testing and repair and maintenance works of returned devices. The layout plan is displayed in Figure 4.3 which can be categorized as a functional layout. Therefore, the new production processes use a combination of functional (upstairs) and product layouts (downstairs). Compared to the current state, hardware development team and support team will acquire the areas left over from the production nearby windows. As seen, the major changes are that the camera module focusing workstation has been moved outside the storage room and the muffled crate for siren testing together with the packing area are moved downstairs. These changes are explained in the further sections below in this thesis.

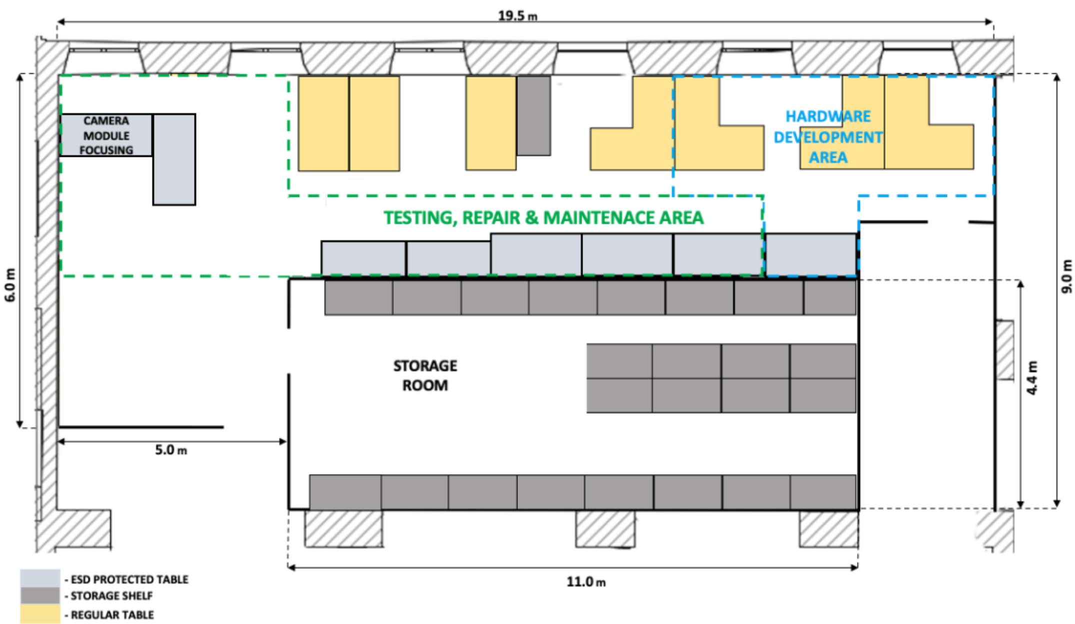


Figure 4.3 Production layout on the second floor (To Be)

Table 4.1 depicts the changes in the area sizes after the new production premises are rented. In total, the summarized size of the rooms where some production related activities are carried out almost doubled from 137,3 m^2 to 271,8 m^2 as 3 new rooms are in addition. To be more exact, then the direct area for production area increased from 106,1 m^2 to 192,6 m^2 and it includes areas both upstairs and downstairs. As seen, the total premises size increased remarkably which is also the basis of growing the production capacity for the future. However, there is more room to expand as the current production premises upstairs will be mainly used for hardware development, support and other activities.

Table 4.1 Comparison of production area sizes

		AS IS		**TO BE**		**DIFFERENCE**	
No.	**Area**	**Size (m^2)**	**Area for production operations (m^2)**	**Size (m^2)**	**Area for production operations (m^2)**	**Size (m^2)**	**Area for production operations (m^2)**
1	Production	68,9	56,1	71,3	71,3	+2,4	+15,2
2	Packing	20,0	20,0	34,2	34,2	+14,2	+14,2
3	Storage room	48,4	30,0	48,4	17,6	0,0	-12,4
4	Testing (upstairs)	-	-	88,9	40,5	+88,9	+40,5
5	Production office	-	-	29,0	29,0	+29,0	+29,0
	TOTAL:	**137,3**	**106,1**	**271,8**	**192,6**	**+134,5**	**+86,5**

4.1 Detector production layout analysis (To Be)

After renting new production premises, the testing and programming of the electronic modules will still be carried out upstairs in the current production area which is turned into testing and repair and maintenance area. Therefore, the electronic modules are taken upstairs to storage section 2.0 where all untested PCB-s are stored. Other detector components are stored in the production room downstairs. Each PCB has its own workstation for testing and programming which means that testing can be done simultaneously. Moreover, the setup time is reduced remarkably as the testers are constantly connected to the computers at the workstation. A big difference compared to the current layout is that the camera module focusing is brought outside from the storage room due to high temperature and noise in storage room caused by the IT technology stored there. Since the camera module focusing is now placed to the corner of the room, darkening blinds are put to the window near the workstation to maintain constant lighting conditions. Adding lenses to the camera module is now done next to the focusing workstation, making the camera module preparation and focusing a separate cell. All tested PCB-s are put into the collection point (CP) which is a specific storage section. Therefore, the workers know which PCB-s are tested and can be brought downstairs to the production room for assembly. The layout size (40,5 m^2) for testing detector PCB-s is indicated in light green colour in Figure 4.4. Also the movement of components and product flow are visualized. Table 4.2 and Table 4.3 describe the movement of both components and products in the testing area. For simplicity, the movement between upstairs and downstairs are not included as this takes place rarely.

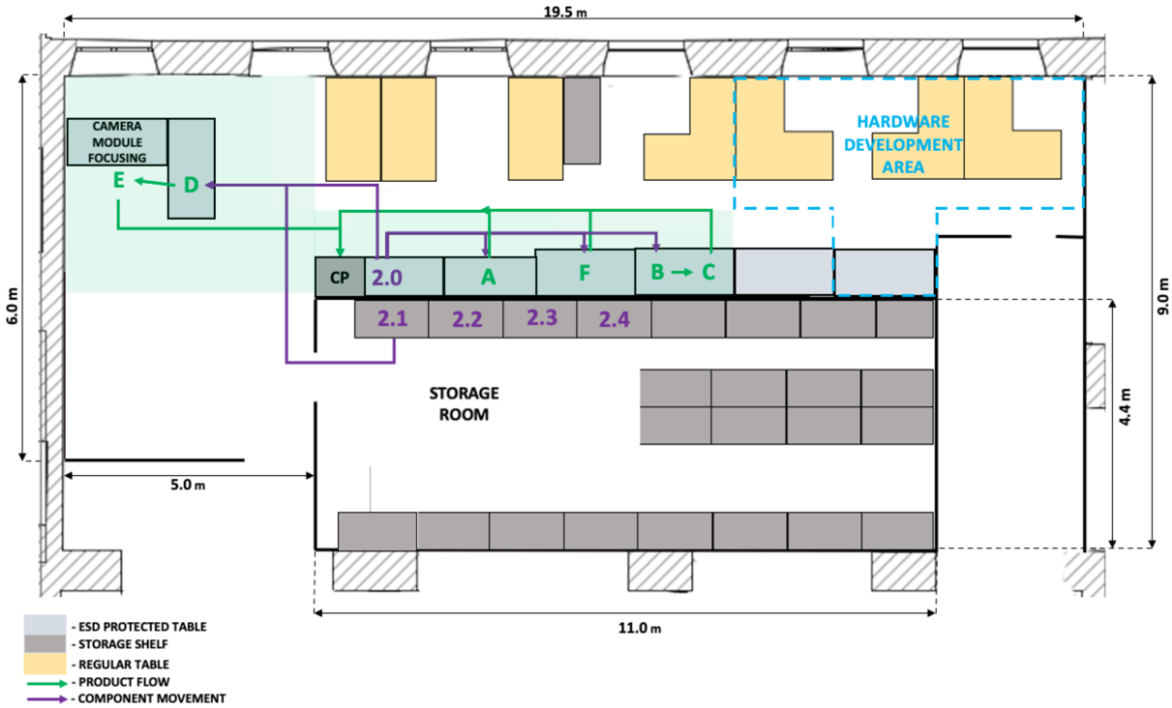


Figure 4.4 Detector production layout in the testing area (To Be)

When the PCB-s are tested and programmed upstairs in the testing area, the detector production continues downstairs. Each production activity has its own workstation equipped with necessary tools and components which are displayed in Figure 4.5 with the size of detector assembly layout (21,9 m^2). For simplicity, the areas for folding the carton package and packing are excluded as these activities are done separately at a packing area which is also cross-used with sirens and bridges. The layout size used for detector production operations are coloured in light green. Both the back and first enclosure start form the corner of the room – workstation with the suction ventilation. Here the clipping and gluing of the enclosures take place. The back enclosure will move towards the exit through several workstations – enclosure preparation, enclosure stacking, production in ERP. Between the workstation there are separate areas for WIP buffers. At the same time the first enclosures move to the right and are prepared on the next table. Assembled first enclosures are stored on a cart which are transported to the final assembly and testing workstation (operation M) when needed. The final products are moved to the packing area with carts. Folding carton packages for the detectors and packing the devices take place in the packing area. The product flow distances between operations are displayed in Table 4.2. For simplicity, the movement between upstairs and downstairs are not included as this takes place rarely. As a result the product flow movement distance reduced from 77,0 meters to 37,0 meters.

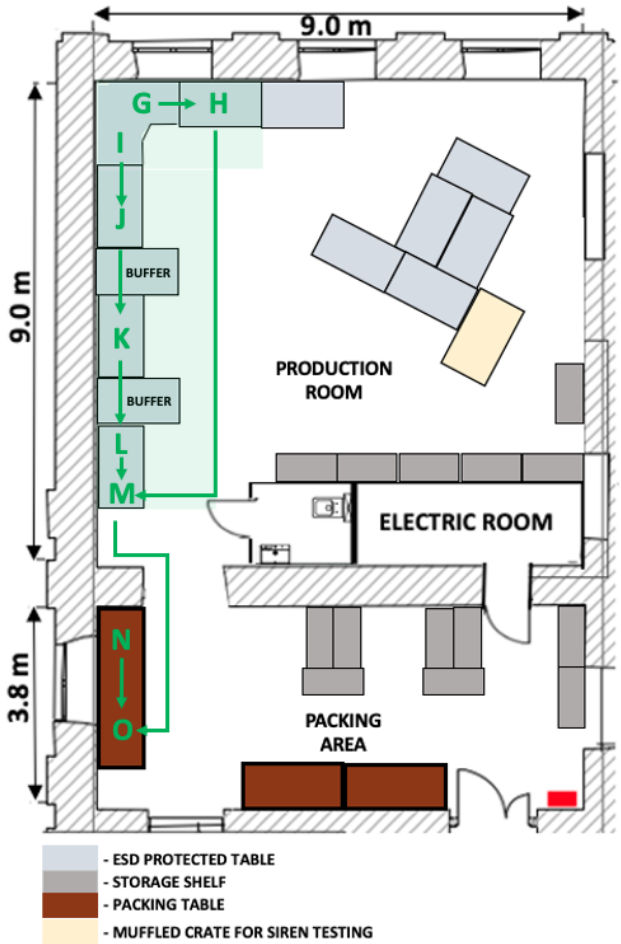


Figure 4.5 Detector production layout on the first floor (To Be)

Table 4.2 Product flow distances of detector production (To Be)

Operation marking	Activity	Movement between operations	Distance (m)
A	PIR module testing	A → CP	3,0
B	Radio module testing & programming	B → C	0,5
C	Radio module configuration & cert loading	C → CP	6,5
D	Camera module - adding lenses	D → E	1,0
E	Camera module focusing	E → CP	3,5
F	IR Flash module testing	F → CP	5,0
G	Enclosure A preparation	G → H	1,0
H	Enclosure A assembly	H → M	6,0
I	Enclosure B preparation	I → J	1,5
J	Enclosure B assembly	J → K	2,0
K	Enclosure B stacking	K → L	2,0
L	Production in ERP	L → M	0,5
M	Final test & assembly	M → O	3,5
N	Folding carton package	N → O	1,0
O	Packing	-	-
	Total: 15 activites		**37,0**

As mentioned, the components for daily production are stored directly in the production room. Also a small quantity of components are stored at each workstation which are refilled if necessary. As a result, the storage sections near the wall need less space. The components at the workstation are refilled with a cart in single pick-ups as currently. At first, components are picked for the storage section which is the farthest away and the worker will move towards the workstation and pick other components on the way. Some workstations, for example camera module focusing, do not need components from the storage section. Instead they need input from the previous workstations. In total 12 different pick-ups are done during the detector production which are displayed in Table 4.3. The total distance travelled reduces approximately a half, from 145,0 meters to 77,0 meters.

Table 4.3 Movement of detector components (To Be)

Pick-up no	Movement to operation	Storage section marking	Components	Distance (m)
1	A	2.0	Untested PCB-s	1,5
2	B & C	2.0	Untested PCB-s	5,5
3	D	2.0	Untested PCB-s	7,0
		2.1	Lenses	
4	F	2.0	Untested PCB-s	4,0
5	G	1.0	Enclosures	6,5
6	H	1.2	Tested PCB-s	10,0
		1.4	Cables, seals	
		1.5	Metal (nuts & bolts)	
7	I	1.0	Enclosures	6,5
8	J	1.4	Cables, seals	9,5
		1.5	Metal (nuts & bolts)	
9	K	1.2	Tested PCB-s	9,5
		1.5	Metal (nuts & bolts)	
10	M	1.4	Cables, seals	7,5
		1.5	Metal (nuts & bolts)	
11	N	1.11	Packing material	6,0
12	O	1.8	Extra equipment	3,5
			TOTAL:	**77,0**

The movement of the components from the storage sections to workstations in the production room are visualized in Figure 4.5. The component movement upstairs in the testing area is displayed in Figure 4.4. The more thicker the movement line is on the figures, the more times the path is being travelled. Storage sections 1.6-1.8 are for extra equipment and sections 1.9-1.11 area for packing materials. For simplicity, storage sections 1.8 and 1.11 are used in distance measurements and calculations.

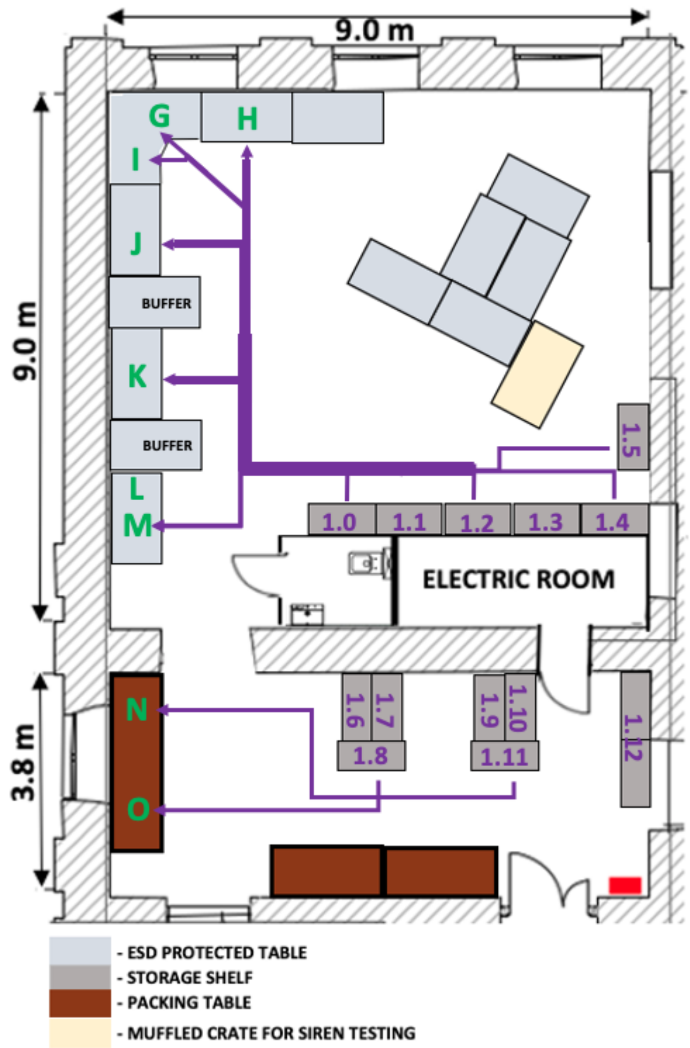


Figure 4.6 Movement of detector components on the first floor (To Be)

4.1.1 Detector production process simulation

In order to understand how changing a production layout and reducing the total movement distance of product flow during the process is affecting productivity a simulation in Tecnomatix was carried out for the new layout. Again the production process was modelled without the folding carton package and packing operations which are carried out in the packing area. The simulation model is displayed in appendix 2. The simulation included the real durations of operations and reduced distances between workplaces until the packing area. Setup times of operations were eliminated as there is a separate workplace for each operation which includes all necessary components, tools, testers etc. Again, for simplification purposes, the simulation was carried out as if every workplace would be manned in order to display the results of reducing the product flow movement distances most clearly. As a result of the simulation, the throughput of the detector production process during an 8-hour working day increased by 1 device, from 54 pcs to 55 pcs.

The workplace utilization in the simulation can be seen in Figure 4.7. The utilization of different workplaces is still not efficient and they are out of balance. However, they have improved a bit compared to the current layout. The bottleneck of the process is still the device production in the ERP system. In reality, all workplaces are not manned. The workers perform operations in batches and move between workplaces as needed. As a result of the simulations of both current detector production layout and new developed detector production layout, it can be said that improving the layout and reducing the product flow movement distance enhances the production efficiency. In reality, the production capacity should increase even a bit more since the current waiting time for a vacant workplace where to carry out the operation and movement between stairs are not included into the simulations for simplicity purposes. However, improving the production processes as a whole and increasing production efficiency also consists of many other aspects such as line balancing, improving technology used in the processes, reducing waste etc. which are separate topics that need additional research and analysing. These topics are not being analysed in the current master thesis. Moreover, the same simulation principles could be used for simulation bridge and siren production processes.

Operation Marking	Production operation	Utilization (%)
A	PIR module testing	44.2%
B	Radio module testing & programming	36.5%
C	Radio module configuration & cert loading	66.0%
D	Camera module - adding lenses	56.2%
E	Camera module focusing	66.2%
F	IR Flash module testing	16.1%
G	Enclosure A preparation	7.4%
H	Enclosure A assembly	66.9%
I	Enclosure B preparation	7.4%
J	Enclosure B assembly	71.9%
K	Enclosure B stacking	65.1%
L	Production in ERP	97.6%
M	Final test & assembly	53.3%

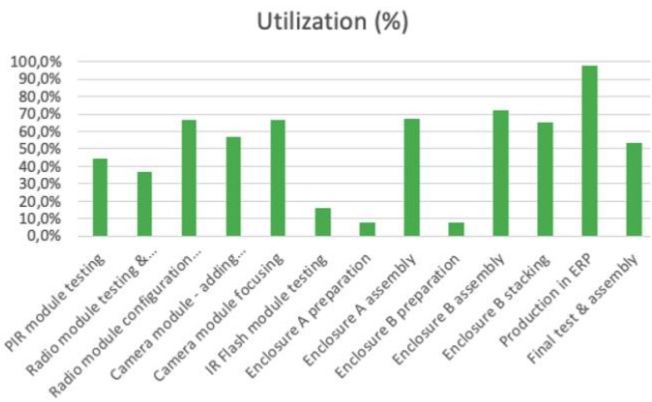


Figure 4.7 Utilization of workplaces (To Be)

4.1.2 As Is and To Be comparison of detector layout

The changes what the new detector layout will bring are displayed in Table 4.4. The product flow and component movement distances will decrease approximately by half. The product flow distance during the production process will reduce 40 meters from current 77,0 meters to 37,0 meters. As a result, unnecessary movement is eliminated making the process more efficient. The distance travelled for picking components from the storage shelves will reduce from 145,0 meters to 77,0 meters as the storage sections are located inside the main production room. Overall the layout size used for detector production will increase approximately 44% as there will be separate workstation for each operation which will increase the production capacity as moving subassemblies and components between different tables to make room for another operation is eliminated. The simulation in Siemens Tecnomatix Plant Simulation software indicated that the daily throughput of the detector production will increase nearly 2%.

Table 4.4 As Is & To Be layout comparison of detector layout

No.	Description	AS IS	TO BE	Difference (m/m^2)	Difference (%)
1	Product flow distance (m)	77,0	37,0	**-40,0**	**-51,9%**
2	Component movement distance (m)	145,0	77,0	**-68,0**	**-46,9%**
3	Layout size (m^2)	43,2	62,4	**+19,2**	**+44,4%**
4	Throughput (pcs, 8-hour working day)	54,0	55,0	**+1,0**	**+1,9%**

4.2 Bridge production layout analysis (To Be)

Bridge production, also testing, will take place only in the main production room downstairs. The main reason for it is the fact that bridge includes only one electronic module which testing is quite time-consuming. Moreover, it is possible to already stack the tested PCB into the prepared enclosure while another PCB is being tested – this is more efficient. The product layout and product flow of bridge production is displayed Figure 4.8 in light red and orange colour. The bridge layout size is approximately 20,4 m^2. This does not include the areas for folding the carton package and packing for simplicity as this working stations are cross-used with folding packages and packing other devices as well. As seen from Figure 4.8, bridge production layout is quite compact and the product moves relatively few. The product flow distances between production operations are displayed in Table 4.5. In total, the product travels 19,5 meters during the production process. For simplicity, the movement between upstairs and downstairs are not included as this takes place rarely.

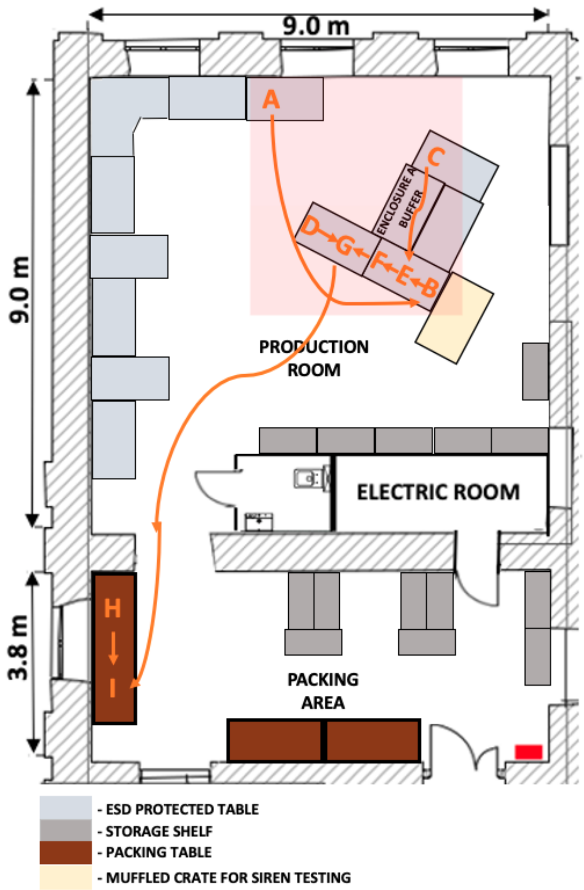


Figure 4.8 Bridge production layout on the first floor (To Be)

Table 4.5 Product flow distances of bridge production (To Be)

Operation marking	**Activity**	**Movement between operations**	**Distance (m)**
A	PCB testing & programming in tester 1	A → B	5,5
B	PCB testing & programming in tester 2	B → E	0,5
C	Enclosure A preparation	C → E	3,0
D	Enclosure B preparation	D → G	0,5
E	Enclosure A stacking	E → F	0,5
F	Production in ERP	F → G	1,5
G	Final assembly	G → I	6,5
H	Folding carton package	H → I	1,5
I	Packing	-	-
	Total: 9 activites		**19,5**

Bridge enclosure preparation is carried out in the top right table in Figure 4.8. This table will be shared also with siren enclosure preparation as most of the components used are the same. Bridges will move to the left on Figure 4.8 and sirens to the right. The prepared bridge first enclosures are stored on the next table which acts as a buffer. If the PCB has passed the tests in tester 1 (operation A) then it is tested in tester number 2. This tester is placed to a workstation where also production in ERP is carried out. Therefore 3 operations are done in one workstation – testing and programming the PCB, stacking it into a prepared first enclosure concurrently testing another PCB and finally registering the bridge in the ERP system – inserting information regarding its serial number, ID number, configuration, customer information etc. Then the bridge moves into the next workstation for final assembly and quality control. Here the first and back enclosures are put together. Back enclosures have been previously prepared in the same workstation and stored on the side of the table. The ready product is transported to the packing area with the cart where it will be packed into previously folded packages or into a custom water- and shockproof transportation cases.

7 different component pick-ups from the storage sections are needed during bridge production process. The distances covered by the 7 component pick-ups are displayed in Table 4.6 and visualized in Figure 4.9. The thicker the movement line is, the more times this path is being travelled during component pick-ups. As mentioned earlier, the component storage sections will be located also in the main production room in order to reduce movement distances. In total, approximately 34,0 meters is covered by transporting components from storage sections to workstations. Storage sections 1.6-1.8 are for extra equipment and sections 1.9-1.11 area for packing materials. For simplicity, storage sections 1.8 and 1.11 are used in distance measurements and calculations. It is important to mention that untested PCB-s will be stored in position T1 which is located on the same table with the first PCB tester. The PCB-s that pass the tests are then directly moved to the workstation where the second tester is positioned.

Table 4.6 Movement of bridge components (To Be)

Pick-up no	Movement to operation	Storage section marking	Components	Distance (m)
1	A	T1	Untested PCB-s	0,5
2	C	1.1	Enclosures	9,0
		1.4	Cables, seals	
3	D	1.1	Enclosures	6,5
		1.5	Metal (nuts & bolts)	
4	E	1.5	Metal (nuts & bolts)	3,5
5	G	1.4	Cables, seals	5,0
		1.5	Metal (nuts & bolts)	
6	H	1.11	Packing material	6,0
7	I	1.8	Extra equipment	3,5
			TOTAL:	**34,0**

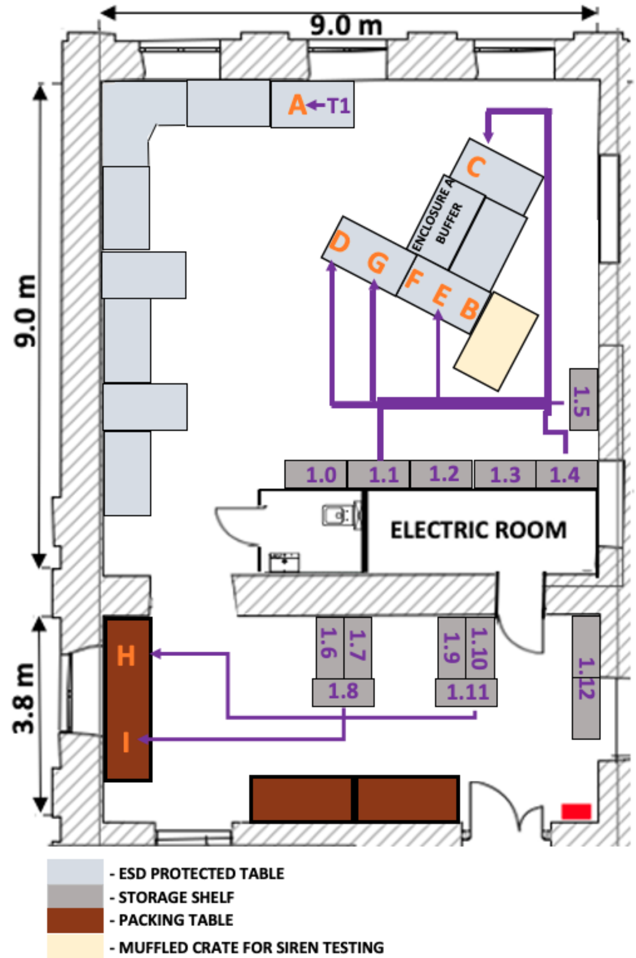


Figure 4.9 Movement of bridge components on the first floor (To Be)

The comparison of the current and to-be bridge production layouts is displayed in Table 4.7. The distance what the product will cover during the production process will decrease by approximately 31,6%, reducing from 28,5 meters to 19,5 meters. The component movement from the storage sections to the workstations will reduce by 61,6%, dropping from 88,5 meters to 34,0 meters as the storage sections are located near the workstations. Since the waste in terms of unnecessary movement is eliminated from the production process, it is more efficient. The new designed bridge production layout is more compact. As a result, the layout size will decrease from 25,4 m^2 to 20,4 m^2.

Table 4.7 As Is & To Be layout comparison of bridge layout

No.	**Description**	**AS IS**	**TO BE**	**Difference (m/m^2)**	**Difference (%)**
1	Product flow distance (m)	28,5	19,5	**-9,0**	**-31,6%**
2	Component movement distance (m)	88,5	34,0	**-54,5**	**-61,6%**
3	Layout size (m^2)	25,4	20,4	**-5,0**	**-19,7%**

4.3 Siren production layout analysis (To Be)

The siren consists of 2 different electronic modules. One of them is also used in detectors which is tested upstairs in the testing area. Therefore, the layout of siren production is located on two floors. The layout size, product flow and component movement upstairs is displayed in Figure 4.10. In conclusion only one operation of the siren production is carried out upstairs. Untested PCB-s are stored in location 2.0. Once they are tested and programmed, the PCB-s are put into the collection point (CP). Here the PCB-s are collected as often as needed and transported downstairs to the production room where the assembly of devices take place. One pick-up can contain enough PCB-s for several days. The product flow and layout size of siren production downstairs is visualized in Figure 4.11 in light blue colour. Simultaneously with testing one of the PCB-s upstairs, connecting the other PCB with a beacon and testing it in the muffled crate can be carried out together with enclosure preparation. It is done downstairs because the muffled crate is also now located downstairs which is also used for the final test of the siren. Therefore, the movement distance of the worker reduces drastically. It is important to mention that the muffled crate will be a bit improved that it would muffle the alarm sound of the siren. The crate will be positioned directly next to the final test table and production in ERP workstation as seen from Figure 4.11.

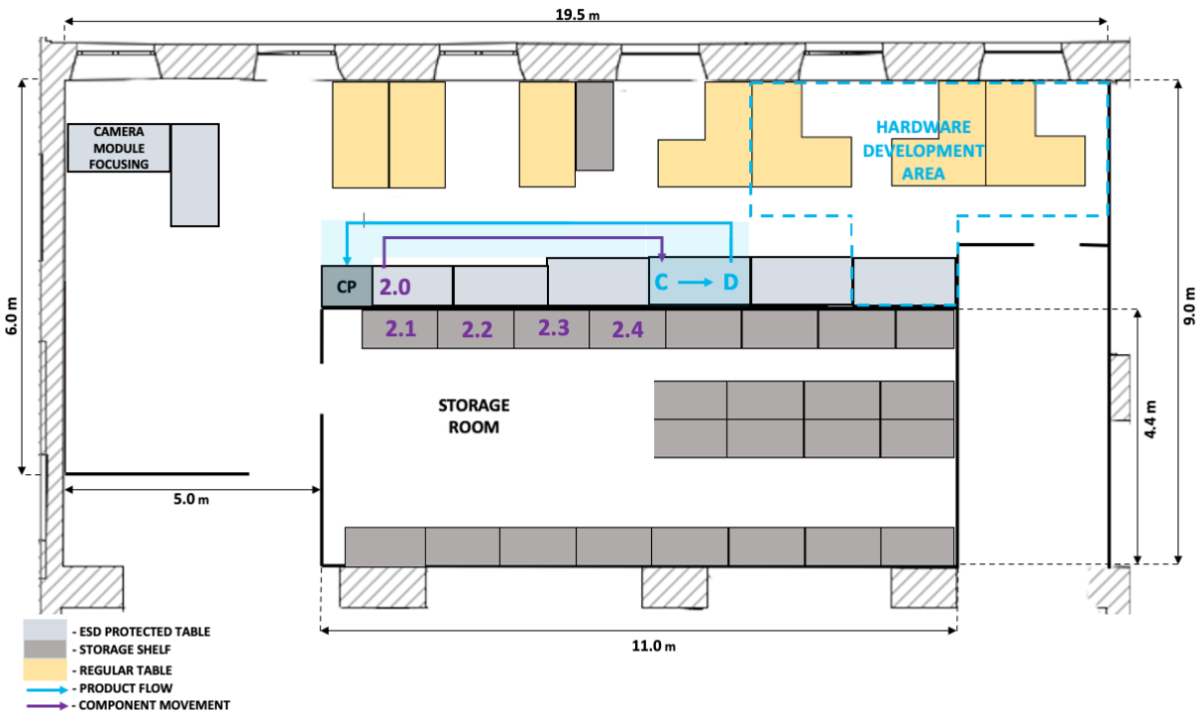


Figure 4.10 Siren production layout on the second floor (To Be)

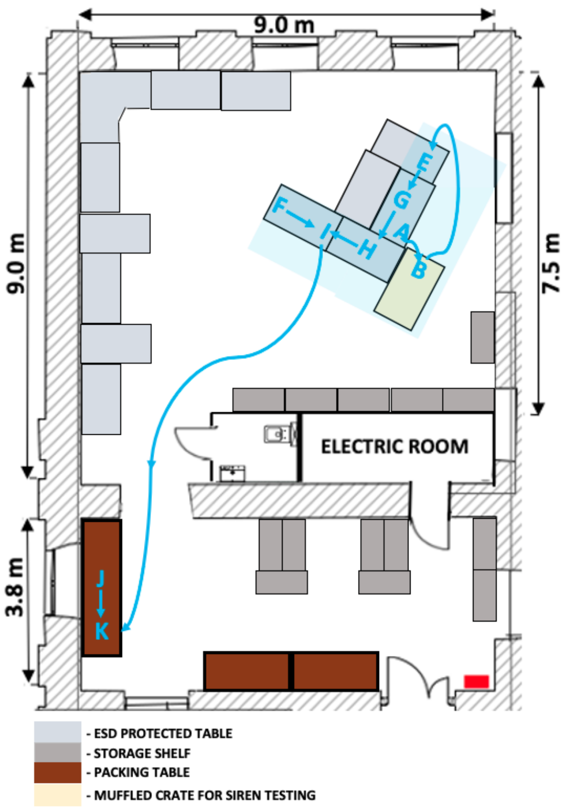


Figure 4.11 Siren production layout on the first floor (To Be)

The first enclosure is prepared at the same workstation as the bridge first enclosure because most of the components used for these operations are the same. The workstation is divided into two – on one side the enclosures are prepared for the siren, on the other side, the enclosures are prepared for bridge. After the first enclosure is prepared it moves to the next workstation for stacking. In this workstation, the PCB that is tested and programmed upstairs is also needed. This table is also for buffer purposes and connecting the one of the PCB-s with the beacon before testing them. Once the siren is stacked then it moves to the next workstation where the production in ERP and final test is carried out, which is also used for bridge production. The assembled siren is again put into the muffled crate which is next to the workstation and activated in order to validate the functionality of the device. All necessary information is filled into the ERP system regarding a certain device – its serial number, ID number, configuration, customer information etc. Then the product moves to the next workstation where previously prepared back enclosures are assembled to the device and a quality control is carried out. If no quality issues arise then the devices are transported to the packing area on carts. The devices are packed into pre-folded packages or custom transportation boxes with its necessary equipment. Based on the information described above, it can be said that the bridge and siren production operations take place in a single work cell. In total, the siren moves between different operations 24,0 meters and the summarized production layout size is approximately 20,3 m^2. For simplicity, the areas for folding the carton package and packing are excluded as these activities are done separately at a packing area which is also cross-used with detectors and bridges. The product movement between different operations are displayed in Table 4.8. For simplicity, the movement between upstairs and downstairs are not included as this takes place rarely. It is important to mention that all distances and area sizes in this chapter (chapter 4) are not measured directly but they are calculated based on the floor plan and equipment size.

Table 4.8 Product flow distances of siren production (To Be)

Operation marking	Activity	Movement between operations	Distance (m)
A	Connecting PCB 1 with beacon	A → B	1,5
B	Testing PCB 1 & beacon	B → E	3,5
C	PCB 2 testing, programming	C → D	0,5
D	PCB 2 cert loading	D → CP	6,5
E	Enclosure A preparation	E → G	1,5
F	Enclosure B preparation	F → I	0,5
G	Enclosure A stacking	G → H	1,5
H	Production in ERP	H → I	0,5
I	Final assembly	I → K	6,5
J	Folding carton package	J → K	1,5
K	Packing	-	-
	Total: 11 activites		**24,0**

The component movements from storage sections to workstations in the testing area and main production room are visualized in fFigure 4.10 and Figure 4.12 and explained inTable 4.9. Storage sections 1.6-1.8 are for extra equipment and sections 1.9-1.11 area for packing materials. For simplicity, storage sections 1.8 and 1.11 are used in distance measurements and calculations. The thicker the movement line is on the figures, the more times this path is being travelled during the component pick-ups. In total, 8 component pick-ups are needed and the components move approximately 42,0 meters from the storage sections to workstations during the pick-ups.

Table 4.9 Movement of siren components (To Be)

<table>
<tr><th>Pick-up no</th><th>Movement to operation</th><th>Storage section marking</th><th>Components</th><th>Distance (m)</th></tr>
<tr><td>1</td><td>A</td><td>1.3</td><td>Untested PCB-s</td><td>4,0</td></tr>
<tr><td>2</td><td>C & D</td><td>2.0</td><td>Untested PCB-s</td><td>5,5</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">E</td><td>1.1</td><td>Enclosures</td><td rowspan="3">8,0</td></tr>
<tr><td>1.4</td><td>Cables, seals</td></tr>
<tr><td>1.5</td><td>Metal (nuts & bolts)</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">F</td><td>1.1</td><td>Enclosures</td><td rowspan="2">6,5</td></tr>
<tr><td>1.5</td><td>Metal (nuts & bolts)</td></tr>
<tr><td>5</td><td>G</td><td>1.5</td><td>Metal (nuts & bolts)</td><td>3,0</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">I</td><td>1.4</td><td>Cables, seals</td><td rowspan="2">5,5</td></tr>
<tr><td>1.5</td><td>Metal (nuts & bolts)</td></tr>
<tr><td>7</td><td>J</td><td>1.11</td><td>Packing material</td><td>6,0</td></tr>
<tr><td>8</td><td>K</td><td>1.8</td><td>Extra equipment</td><td>3,5</td></tr>
<tr><td></td><td></td><td></td><td>TOTAL:</td><td>42,0</td></tr>
</table>

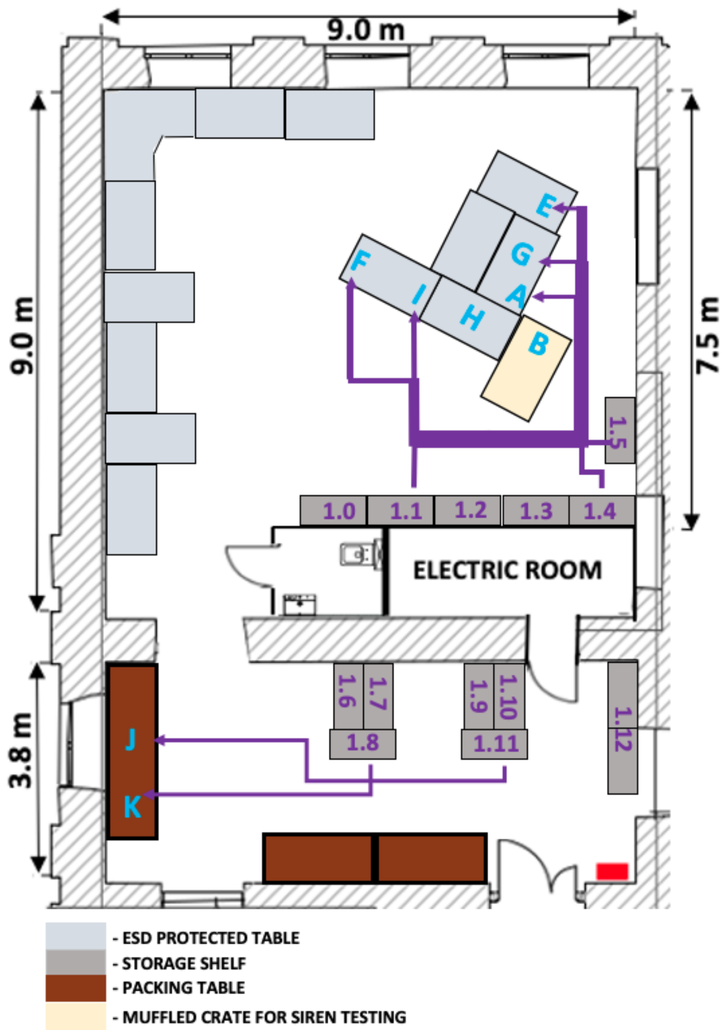


Figure 4.12 Movement of siren components on the first floor (To Be)

Different siren production layout parameter changes are displayed in Table 4.10. As a result of the new design of the layout, both the total product flow distance and component movement distance are reduces more than a half. The product flow distance drops from 52,5 meters to 24,0 meters and component movement from 88,5 meters to 42,0 meters. The layout area size has decreased by a third – now covering only 20,3 m^2. In conclusion, the new layout is more efficient and compact than the current one.

Table 4.10 As Is & To Be layout comparison of siren layout

No.	Description	AS IS	TO BE	Difference (m/m^2)	Difference (%)
1	Product flow distance (m)	52,5	24,0	**-28,5**	**-54,3%**
2	Component movement distance (m)	88,5	42,0	**-46,5**	**-52,5%**
3	Layout size (m^2)	31,6	20,3	**-11,3**	**-35,8%**

4.4 Workplace design and standardization

The new designed production layout is displayed and explained previously in the current chapter. Most of the production operations have their own certain workstations, which reduces cross-usage of a workstation, excess movement of product and component and makes the production room more clean, clear and visually easier to manage. In order to benefit more from the layout design, it is also important to improve and design the workstations using different tools and principles which enhance the production layout design and efficiency.

The general concept of the designed workstation is displayed in Figure 4.13. Important parts of the workstation are a height-adjustable table, rack for storing components, drawer and additional lighting. However, the real workstations will be modified based on the needs, requirements and production peculiarities of Defendec. It means that suitable tables, racks, etc. are purchased separately and put together as one workstation to have the best results.

Figure 4.13 General workplace concept [33]

By default the suitable tables to use in workstations are measured 150 x 80 cm. If electronic modules are also handled in the workstation, then the tables are covered with ESD protected table mats. Ten additional tables are needed for the new production premises, each costs approximately 200 euros [34]. The shelf for storing components is a kanban type which is positioned under an angle and where components move forwards due to gravitation. One shelf is enough for a single workstation to store enough components. Under the table, one drawer is added. This is for storing necessary tools for the operation carried out in the workstation and the manual which contains instructions and best practices how to do the operation. As a result, the table has more free space and is more clear. Additional lighting will be installed over the workstations in order to ensure sufficient lighting conditions.

Visual management principles will be implemented in production premises in order to clearly and simply share information. Firstly, each device is assigned with a certain colour, for example, purple for detectors, orange for bridges and blue for sirens. This colour is used for indicating and marking everything that is related to the production process of each device. Overall, every workstation is assigned with unique ID which is connected with a certain production operation that takes place in the workstation. Above each workstation a coloured sign is placed which indicates the workstation ID and operation description and the device type which the operation is related to. In that way it is easy to notice and understand what operations are taking place in which workstation. An example of the workstation sign is displayed in Figure 4.14, which indicates that detector back enclosure assembly is carried out in workstation D03.

Figure 4.14 Visual displays used in production

If previously the component boxes were shared by several workstations and moved between them according to need then now each workstation will have its own permanent component boxes which are stored on the kanban shelf. This eliminates the component pick-up before the start of an operation and saves time. Every component box has a special label attached to it, which is again colour-coded and has information about component article number, barcode and workstation ID. In that way a component box is connected to a certain workstation. An example of a label attached to each component box is displayed in Figure 4.14 which indicates that the box contains article number 53301 from workstation S01 that is part of siren production process. Additionally, the component boxes are divided into two sections by a divider. If the first section of components within the box is used during operations then the divider is removed and components from the second section move forward due to gravitation. The dividers are also labelled with a stickers that contain information about their components – article number, serial number, quantity to refill and workstation ID. Based on that, a certain component box will be refilled. Finally, the component shelves are also labelled with article number labels they should store. In that way it is easy to notice if any component box is missing from its original position.

The drawer under the table also contains elements of visual management. Firstly, it contains a simple manual with photos that describe how the operation is carried out. It helps to remind the process if necessary. Moreover, the drawer includes also a list of tools that are used in the workstation. Each tool is also color-coded and marked with a label indicating the workstation ID where it is from. Additionally, the drawer fits a shadow board of the tools which define where a certain tool should be located when it is not in use. As a result, missing tools can be identified quickly.

Also, the ergonomic aspects were taken into consideration in the design process of a workplace, e.g. adjustable chairs and tables, extreme arm reaches and awkward body positions are avoided, additional lighting is installed. As suggested by theory, the components and tools are located as close to the point of use [12], [29]. The designed workplace layout is displayed in Figure 4.15 with the ergonomic reach zones. As mentioned previously, the default table measures will be 150 cm x 80 cm. Approximately 15-20 cm above the table, there is a kanban shelf for components installed. Therefore, there is plenty of space to carry out the production operations (green area in Figure 4.15) and the components can be picked the arms reach within the occasional work zone (yellow area in Figure 4.15). Thus, extreme reaches of arm are avoided. Due to sufficient lighting, the headaches and fatigue of workers are prevented.

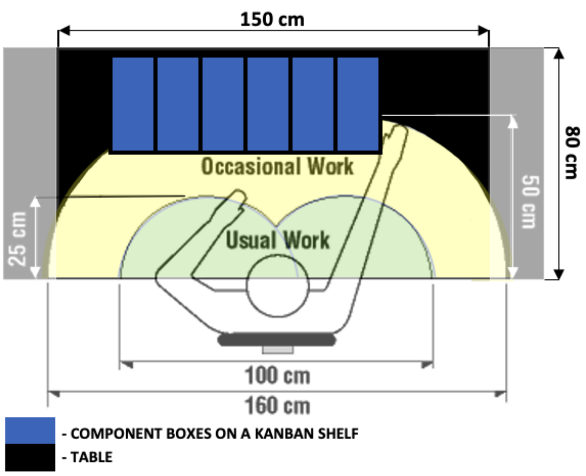


Figure 4.15 Ergonomic reach zones of a workplace [35] (modified by author)

5 FINANCIAL FEASIBILITY

In order to calculate the financial feasibility of the new production premises, production layout and workplace layout, a break-even analysis is performed. It is calculated from the aspect of throughput increase of the detector production. These principles can also be used for bridge and siren throughput increase due to layout change and reduced product flow distance.

Firstly, it is necessary to find the total costs related to moving into new production premises downstairs. It involves construction works to make the premises suitable for production purposes, including ESD protected flooring installation, suction ventilation, cabling, lighting etc. The total cost for the construction works is estimated to be approximately 10 000 €. Moreover, it is necessary to buy additional tables, storage sections, tools, computers etc. since everything will not be moved from the current premises to the new ones. These are one-time costs that are based on the retail prices of the goods [36], [37], [38], [39]. All costs are displayed in Table 5.1 with the quantity needed and cost per item which are multiplied and then the final cost is added together. The total cost of implementing the new production layout is around 17 820 €.

Table 5.1 Total cost of new layout

No.	Description	Qty (pcs)	Cost (€)	Total (€)
1	Construction works	1	10 000	**10 000**
2	Storage section kits	6	125	**750**
3	Tables	10	205	**2 050**
4	Other furniture (chairs, shelves)	1	850	**850**
5	ESD equipment	1	550	**550**
6	Production computer kit	2	1 400	**2 800**
7	Tools	1	700	**700**
8	Component boxes	20	6	**120**
			TOTAL:	**17 820**

In chapter 4.1 it is found that the detector layout will increase by 19,2 m^2 from 43,2 m^2 to 64,4 m^2. For ease of calculations the renting price of a m^2 is set to 8 €. As a result, the monthly renting cost for the area size of detector production layout will increase by 153,5 €:

$$Additional\ montly\ rent\ cost = layout\ size\ increase * m^2\ rent\ price = 19{,}2 * 8{,}0 = 153{,}6\ € \qquad (5.1)$$

If this cost is divided by 30 days, the additional rent cost of a single day for the detector production layout is found, which is 5,12 € per day.

As a result of the simulations carried out in Siemens Tecnomatix Plant Simulation software, it is found that implementing the new layout and reducing the product flow distances will increase the daily throughput of detector production process by 1 device to 55 detectors in an 8-hour workday.

Now the additional rent cost for a single day is divided between the number of detectors produced in a day.

$$Additional\ rent\ cost\ per\ detector = \frac{single\ day\ renting\ cost}{daily\ througput} = \frac{5{,}12}{55} \approx 0{,}09\ €\ per\ detector \qquad (5.2)$$

For confidentiality reasons, the current profit margin of 1 detector is set to 100 euros in calculations. If the additional rent cost per detector is deducted from the current profit margin, a corrected profit margin is found for each detector sold in case of the new production layout.

$$Corrected\ profit\ margin = 100 - 0{,}09 = 99{,}91\ €\ per\ detector \qquad (5.3)$$

As a result, the break-even point of moving and implementing the new production layout is found through the number of additional detectors needed to be manufactured due to daily throughput increase:

$$Break\text{-}even\ point = \frac{Implementation\ cost\ of\ new\ layout}{profit\ margin\ per\ detector} = \frac{17\,820}{99{,}91} = 178{,}36 \approx\ 179\ additional\ \ detectors \qquad (5.4)$$

As the daily throughput increased by 1 device then the additional 179 detectors are also manufactured in 179 working days. By multiplying the working days with daily throughput, a total number of detectors needed to be manufactured until the break-even point is found which is 9845 detectors.

$$Break\text{-}even\ point = daily\ throughput * 179\ workdays = 55 * 179 = 9845\ detectors\ in\ total \qquad (5.5)$$

It is important to mention, that this is the break-even point from just the detector production aspect. In reality, the production capacity of sirens and bridges will also increase. If to take into consideration the break-even points of also siren and bridge production and add them up then the overall break-even point will be achieved with even smaller number of detectors manufactured. In sum, the calculations indicate that implementing the new production layout is financially feasible and beneficial as it will increase the production capacity which is with critical importance in order to deliver the future order quantities to customers on time.

SUMMARY

The aim of the master thesis was to develop a new and more efficient production layout for Defendec OÜ in order to cope with the increased demand for products and continue to deliver customer orders on time. As the current production layout was designed at a time when the production volumes were more than 10 times lower and the number of employees has increased more than double in the meantime, the current production premises have become too small and insufficient. The company now has a plan to expand its production to new premises inside the same building to increase production capacity. For that, the current production layout was observed and analysed.

As a result of the current state analysis, several inefficiencies were identified. One of the main problems is that the workplaces are cross-used for production of different devices due to lack of space which results in unnecessary movement and motion of moving WIP in order to free up space for carrying out other production activities. Also, the product flow distances and component movement are unreasonably long. Moreover, the current production premises are located on the 2nd floor and there is no elevator.

The thesis focused on layout planning on two levels: the layout of facilities inside the production department and the layout of individual workplaces. Taken into consideration the production process peculiarities, a hybrid production layout was designed for the production premises which combined elements of product layout for the assembly on the first floor and functional layout for testing and programming the PCB-s on the second floor. Each production operation will have a certain workplace which eliminates the unnecessary motion, transportation and time of looking for tools, components or setting up testers.

The product flow distance of a detector is reduced by approximately 52%, of a bridge by approximately 32% and of a siren approximately 54%. The total component movement distance during production processes is reduced due to more optimized layout as needed components are stored in production room closer to the workplaces. In the detector production process the total component movement is reduced by approximately 47%, in bridge production process by approximately 62% and in siren production process by approximately 53%. The layout size where the production operations of bridges take place is decreasing approximately by 20%. The size of the siren production layout decreases by approximately 36%. The layout sizes decrease as the workplaces are positioned more compact. However, the layout for detector production is increased by approximately 44% as production operations are divided into different workstations and the testing of PCB-s take place in the testing area.

The production process and layout of the detector was analysed further as it has the highest production volume. A simulation was conducted using Siemens Tecnomatix Plant simulation software to understand how the process efficiency and throughput are affected by the layout change and reduced product flow distance. The outcome of the simulation was that daily throughput will increase by 1,9% or one additional detector in an 8-hour workday which is less than the author had anticipated. On the other hand, the author emphasizes that production optimization and making the production more efficient consists of many different aspects out of which layout design and reduced product flow form only a small part. Other aspects such as reducing waste, line balancing and increasing technological capabilities of production tools are separate topics that are not being analysed in the current thesis.

Additionally, a general concept of the workplace layout was developed. It included kanban shelves for components, defined places for tools and production manuals etc. It specifies exactly where tools and components are located. The author suggested implementing several principles of improvement tools such as standardization and visual management that enhance the production efficiency and enable clearer overview of the production. For example, using color-coding for marking workplaces, tools and component boxes.

A break-even point of implementing the new layout was calculated based on the daily throughput increase of the detector production. The outcome indicated that manufacturing 1 additional detector per working day due to increased production throughput is needed during a period of 179 working days, assuming that there is sufficient demand for detectors. Since the increased daily throughput is 55 detectors, then within the period of 179 working days it is necessary to manufacture 9845 detectors. In reality, the break-even point is even a smaller number of additional detectors needed to be manufactured since there will be a daily throughput increase for also sirens and bridges.

In conclusion, implementing the new production layout is financially feasible and beneficial as it will increase the production capacity and prepares the production department to cope with the production forecasts of upcoming periods. It is important to mention that all production related data in numbers has been multiplied with a certain coefficient for confidentiality reasons. In the opinion of the author, the thesis was successful and the outcome of the thesis will be used when expanding to additional production premises.

KOKKUVÕTE

Käesoleva magistritöö eesmärgiks oli välja töötada Defendec OÜ uus ja tõhusam tootmise põhiplaan, mis aitab toime tulla suurenenud nõudlusega toodete järele ning jätkata klientidele tellimuste õigeaegset tarnimist. Kuna praegune tootmise põhiplaan on välja töötatud ajal, kui tootmismahud olid rohkem kui 10 korda väiksemad ning vahepealsel ajal on töötajate arv rohkem kui kahekordistunud, on praegused tootmisruumid jäänud väikseks ja ennast ammendunud. Tootmisvõimsuse suurendamiseks plaanib ettevõte tootmisega laieneda uutele pindadele, mis asuvad samas hoones. Selles vaadeldi ja analüüsiti praegust tootmise põhiplaani.

Hetkeolukorra analüüsi tulemusena tuvastati mitu ebatõhusust. Üheks peamiseks probleemiks on ruumipuuduse tõttu töökohtade ristkasutamine erinevate seadmete tootmiseks, mistõttu esineb pooleliolevate tööde üleliigset liigutamist, et teha ruumi teistele tootmistegevustele. Samuti on tootevoo ja komponentide liikumise kogudistantsid ebamõistlikult pikad. Lisaks asuvad praegused tootmisruumid teisel korrusel ning hoones puudub lift.

Töös keskenduti paigutuse planeerimisele kahel tasandil: tootmisosakonna sisemiste objektide paigutus ja üksikute töökohtade paigutus. Võttes arvesse tootmisprotsessi eripärasid, kavandati tootmisruumide jaoks hübriidne tootmise põhiplaan, mis kombineerib tootepõhiplaani elemente esimesel korrusel, kus tehakse montaaži ning funktsionaalse põhiplaani elemente teisel korrusel, kus testitakse ja programmeeritakse trükkplaate. Iga tootmisoperatsiooni läbiviimiseks hakkab olema kindel töökoht, mis hoiab ära üleliigse liikumise, transpordi ning aja, mis kulub tööriistade või komponentide otsimiseks või testrite seadistamisele.

Detektori tootevoog väheneb ca 52%, bridge'i tootevoog ca 32% ning sireeni tootevoog ca 54%. Kuna vajalikud komponendid ladustatakse tootmisruumis töökohtadele lähemal, siis väheneb optimeerituma põhiplaani tõttu tootmisprotsessi käigus komponentide liikumisdistants. Detektori tootmisprotsessis väheneb komponentide liikumine ca 47%, bridge'i tootmisprotsessis ca 62% ja sireeni tootmisprotsessis ca 53%. Põhiplaani pindala, kus viiakse läbi bridge'i tootmisega seotud tegevusi, väheneb ca 20%. Sireeni põhiplaani pindala väheneb ca 36%. Põhiplaani suurused vähenevad, kuna töökohad on paigutatud kompaktsemalt. Samas suureneb detektori tootmiseks kasutatud põhiplaan ca 44%, kuna tootmisoperatsioonid on jagatud erinevatesse töökohtadesse ning trükkplaatide testimine toimub testimisalas.

Täiendavalt analüüsiti detektori tootmisprotsessi ja tootmise põhiplaani, kuna selle tootmismaht on kõige suurem. Siemens Tecnomatix tehase simulatsioonitarkvara abil viidi läbi simulatsioon, et mõista, kuidas mõjutavad protsessi tõhusust ja läbilaskevõimet põhiplaani muutmine ja tootevoo distantsi vähendamine. Simulatsiooni tulemuseks oli, et päevane läbilaskevõime suureneb 1,9% ehk 8-tunnise tööpäeva jooksul toodetakse üks detektor rohkem, mis oli autori eeldatust vähem. Samas rõhutab autor, et tootmise optimeerimine ja tõhusamaks muutmine koosneb paljudest erinevatest aspektidest, millest põhiplaani kujundamine ja tootevoo vähendamine moodustavad vaid väikse osa. Muud aspektid, näiteks raiskamiste vähendamine, tootmisliini balansseerimine ja tootmisvahendite tehnoloogilise võimekuse suurendamine, on eraldi teemad, mida antud töös ei analüüsita.

Lisaks töötati välja töökoha paigutuskontseptsioon. See sisaldas kanban riiuleid komponentide jaoks, kindlaksmääratud kohti tööriistade ja tootmisjuhendite jaoks jne. See määrab täpselt kindlaks, kus komponendid ja tööriistad asuvad. Autor soovitas rakendada mitmeid parendusmeetmete printsiipe, nagu standardiseerimine ja visuaalne juhtimine, mis parandavad tootmise tõhusust ja võimaldavad selget ülevaadet tootmisest. Näiteks värvikoodide kasutamine töökohtade, tööriistade ja komponendikarpide märgistamiseks.

Uue põhiplaani juurutamise tasuvuspunkt arvutati detektori tootmise päevase läbilaskevõime suurenemise alusel. Tulemus näitas, et päevase suurenenud tootmisvõimekuse tõttu on tarvis toota 1 täiendav detektor 179-tööpäevase perioodi jooksul, eeldusel, et detektorite järele on piisav nõudlus. Kuna suurenenud päevane läbilaskevõime on 55 detektorit, siis on vaja 179 tööpäeva jooksul valmistada 9845 detektorit. Tegelikkuses on tasuvuspunti saavutamiseks tarvis veelgi vähem täiendavaid detektoreid toota, kuna ka sireenide ja bridge'ide päevane läbilaskevõime suureneb.

Kokkuvõttes on uue tootmise põhiplaani rakendamine finantsiliselt tasuv ja kasulik, kuna see suurendab tootmisvõimsust ja valmistab tootmisosakonda ette toime tulema tulevaste perioodide tootmisprognoosidega. Oluline on mainida, et kõik tootmisega seotud arvandmed on konfidentsiaalsuse tõttu läbi korrutatud teatud koefitsiendiga. Autori arvates oli lõputöö edukas ja lõputöö tulemusi kasutatakse uutele tootmispindadele laienemisel.

LIST OF REFERENCES

[1] "ReconEyez homepage," [Online]. Available: https://reconeyez.com. [Accessed 26 March 2021].

[2] "Defendec homepage," [Online]. Available: https://www.defendec.com. [Accessed 1 February 2021].

[3] Defendec OÜ, „Annual Financial Statements," 2010-2020.

[4] International Electrotechnical Comission, *Degrees of protection provided by enclosures (IP Code) standard,* 2013.

[5] "European Commission homepage," [Online]. Available: https://ec.europa.eu/growth/single-market/ce-marking_en. [Accessed 15 February 2021].

[6] L. Wilson, How to Implement Lean Manufacturing, New York: McGraw Hill, 2010.

[7] C. C. Bozarth and R. B. Handfield, Introduction to Operations and Supply Chain Management, Harlow: Pearson, 2016.

[8] L. Krajewski, M. Malhotra and L. Ritzman, Operations Management - Processes and Supply Chains, Harlow: Pearson, 2016.

[9] N. Slack and A. Brandon-Jones, Operations Management, Harlow: Pearson, 2019.

[10] "International Organization for Standardization homepage," [Online]. Available: https://www.iso.org/standard/62085.html. [Accessed 15 February 2021].

[11] Defendec OÜ, "Quality manual," Tallinn, 2018.

[12] J. R. Evans, Applied Production and Operations Management: Fourth edition, St. Paul: West Publishing Company, 1993.

[13] R. Wild, Essentials of Production and Operations Management, London: Cassell, 1995.

[14] W. P. Stevenson, Operations Management, New York: McGraw Hill, 2018.

[15] J. Heizer, B. Render and C. Munson, Operations Management - Sustainability and Supply Chain Management, Harlow: Pearson Education Inc, 2017.

[16] S. A. Kumar and N. Suresh, Operations Management, New Delhi: New Age International (P) Ltd, 2009.

[17] N. Slack and A. Brandon-Jones, Operations and Process Management - Principles and Practice for Strategic Impact, Harlow: Pearson Education Ltd, 2018.

[18] S. Gupta ja M. Starr, Production and Operations Management Systems, Boca Raton: CRC Press, 2014.

[19] R. F. Jacobs and R. B. Chase, Operations and Supply Chain Management, New York: McGraw-Hill Education, 2018.

[20] A. Greasley, Operations Management, London: Sage Publications Ltd, 2008.

[21] R. S. Russell and B. W. Taylor, Operations Management - Creating Value Along the Supply Chain, John Wiley and Sons, 2011.

[22] P. Ledbetter, The Toyota Template. The Plan for Just-In-Time and Culture Change Beyond Lean Tools, Boca Raton: CRC Press, 2018.

[23] M. Gobetto, Operations Management in Automotive Industries, Turin: Springer, 2014.

[24] Bloomsbury Information Ltd, Effective Operations and Performance Management, London: Bloomsbury Information Ltd, 2010.

[25] D. Willis, Process Implementation through 5S - Laying the Foundation for Lean, Boca Raton: CRC Press, 2016.

[26] J. K. Liker and D. Meier, The Toyota Way Fieldbook, New York: McGraw-Hill, 2006.

[27] C. Protzman, F. Whiton and D. Protzman, Implementing Lean. Twice the Output with Half the Input!, New York: Routledge, 2019.

[28] R. Küttner, Nüüdistootmise Õpetus, Tallinn: TTÜ Kirjastus, 2016.

[29] J. M. Walker, Handbook of Manufacturing Engineering, New York: Marcel Dekker Inc., 1996.

[30] A. Porter, Operations Management, Albert Porter & Ventus Publishing, 2009.

[31] "Siemens homepage," [Online]. Available: https://www.plm.automation.siemens.com/global/en/products/manufacturing-planning/plant-simulation-throughput-optimization.html. [Accessed 19 May 2021].

[32] J. Nicholas, Lean Production for Competitive Advantage. A Comprehensive Guide to Lean Methods and Management Practices., Boca Raton: CRC Press, 2018.

[33] "Laoekspert homepage," [Online]. Available: https://www.laoekspert.ee/e-pood/pakkelauad-toolauad-laminaatkattega-k247. [Accessed 16 May 2021].

[34] „AJ tooted webpage," [Võrgumaterjal]. Available: https://www.ajtooted.ee/ladu-ja-toostus/tookoda-toostus/toolauad/toolaud/463833-19439584.wf?productId=19439503#delivery_and_payment. [Kasutatud 20 May 2021].

[35] "Canadian Centre for Occupational Health and Safety," [Online]. Available: https://www.ccohs.ca/oshanswers/ergonomics/standing/standing_basic.html. [Accessed 16 May 2021].

[36] Laoekspert OÜ, „Storage shelves Proff," [Võrgumaterjal]. Available: https://www.laoekspert.ee/e-pood/laoriiulid/laoriiulid-peenkaubale-proff-150-200kgtasap-k76. [Kasutatud 20 May 2021].

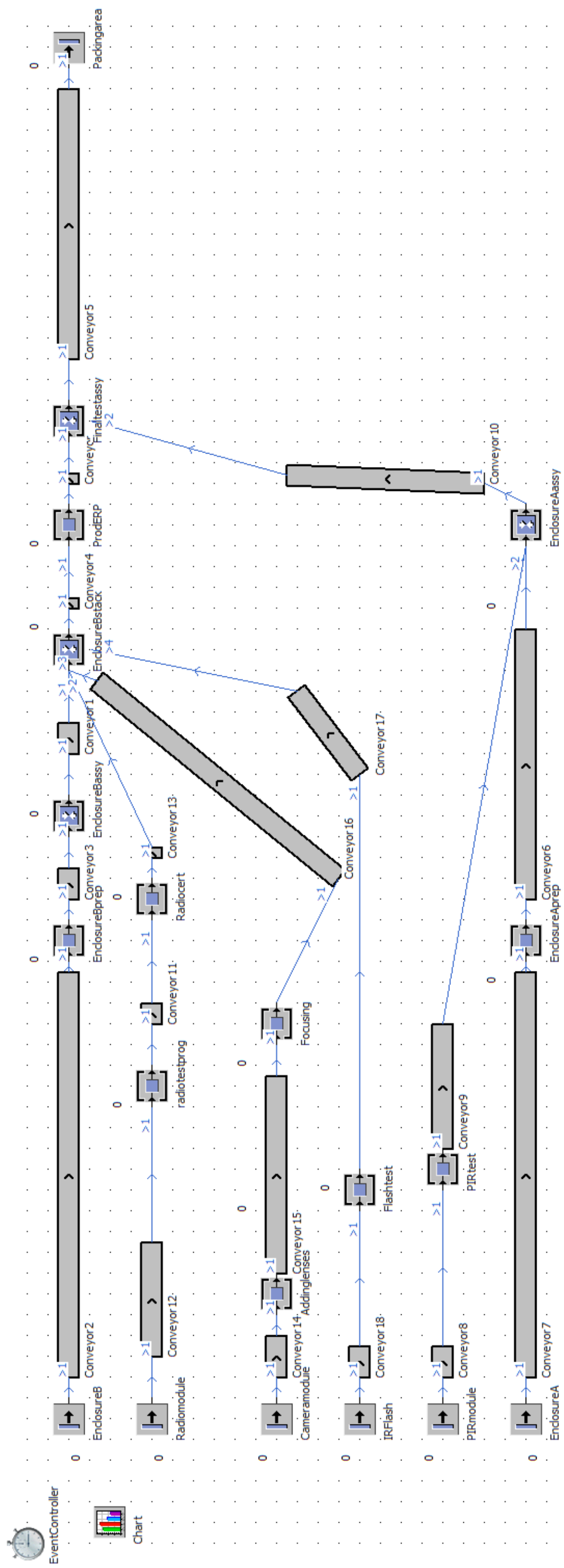
[37] AJ Tooted AS, "Worktable Robust," [Online]. Available: https://www.ajtooted.ee/ladu-ja-toostus/tookoda-toostus/toolauad/toolaud/463833-19439584.wf?productId=19439503#delivery_and_payment. [Accessed 20 May 2021].

[38] Elfa Distrelec OÜ, "Panasonic cordless screwdriver," [Online]. Available: https://www.elfadistrelec.ee/et/cordless-screwdriver-ah-nm-panasonic-industry-europe-ey-7410-la1c/p/18037731?q=180-37-731+&pos=1&origPos=1&origPageSize=50&track=true. [Accessed 20 May 2021].

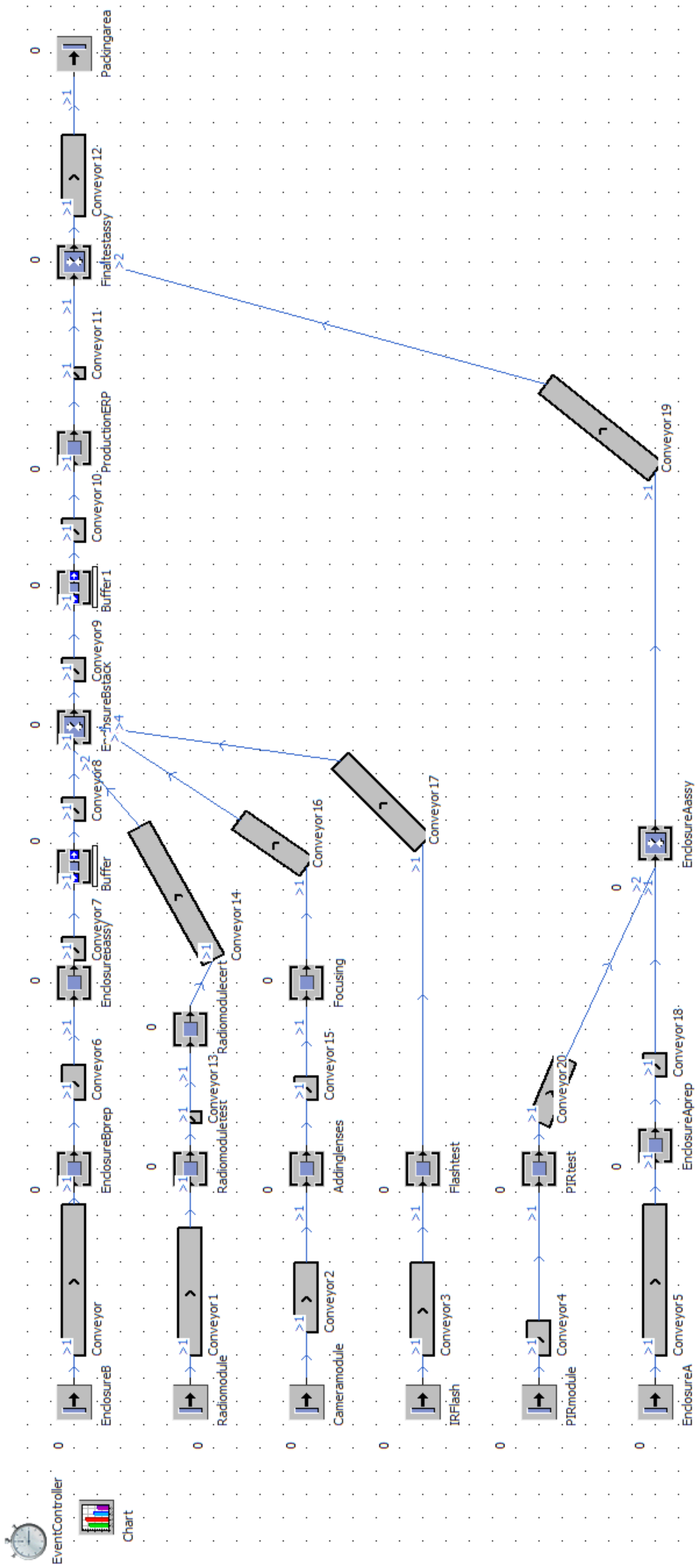
[39] AJ Tooted AS, "Component box Reach," [Online]. Available: https://www.ajtooted.ee/ladu-ja-toostus/ladu/laokarbid/laokarp/463779-19434578.wf?productId=19434586. [Accessed 20 May 2021].

APPENDICES

APPENDIX 1 As Is simulation of detector production process



APPENDIX 2 To Be simulation of detector production process



GRAPHICAL MATERIAL

Graphical material 1: Route to current production premises