Samir Talat

# The Implementation of a Cobot to Enhance Production Testing

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# Abstract

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| Author: | Samir Talat |
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This project was commissioned by Aidon Oy, to enhance their production testing capabilities at Aidon Customization Centre Vantaa by utilizing collaborative robotics. The aim of this thesis work was to design and implement a new production layout which would be able to host the desired cobot-cell. The project also looked at areas of improvement in the overall process.

Lean philosophy and methodologies, such as DMAIC, were applied in this project to design and optimize the new layout as well as other parts of the process. This thesis also covers the deployment of the desired cobot-cell. The project started by collecting data on the old production process and its layout, in order to assess its efficiency and possible areas of improvement. The collected data was then used to make a baseline for a comparison with the final changes and results.

The designed layout and the cobot-cell were successfully implemented to ACC's production process. Due to time limitations, the achieved results, for the most part, are only estimates. Considering the layout changes alone, no significant increase in efficiency of the production process was possible to be made, as it is already well-optimized. However, the implementation of the cobot allows for at least a 22% gain in efficiency of the production testing.

Keywords: Cobot, Lean, Efficiency

# Tiivistelmä

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Tämän työn tilaajana oli Aidon Oy, jonka toiveena oli parantaa Aidon Customization Centre Vantaan tuotantotestauskykyä hyödyntämällä yhteistyörobotiikkaa. Tämän opinnäytetyön tavoitteena oli suunnitella uusi tuotannon layout, johon halutun yhteistyörobotin sijoittaminen olisi mahdollista. Työssä tarkasteltiin myös muita tuotannon prosessin parannuskohteita.

Lean-filosofiaa ja menetelmiä, kuten DMAIC-menetelmää, sovellettiin tässä tutkimuksessa uuden layoutin suunnitellussa sekä tuotannon prosessin muiden vaiheiden optimoinnissa. Tässä opinnäytetyössä käsiteltiin myös halutun kobottisolun käyttöönottoa. Tutkimus aloitettiin keräämällä tietoa vanhasta tuotantoprosessista ja sen layoutista, jotta voitiin arvioida sen tehokkuutta ja mahdollisia parannuskohteita. Kerättyjen tietojen avulla tehtiin lähtökohta toteutukselle, jota voitiin verrata lopullisiin muutoksiin ja tuloksiin.

Suunniteltu layout ja kobottisolu otettiin onnistuneesti käyttöön ACC:n tuotantoprosessissa. Aikarajoitusten vuoksi saavutetut tulokset ovat suurimmaksi osaksi vain arvioita. Pelkästään layout-muutosten perusteella tuotantoprosessin tehokkuutta ei voitu lisätä, koska se oli jo valmiiksi hyvin optimoitu. Kobotin käyttöönotto mahdollistaa kuitenkin vähintään 22 %:n lisäyksen tuotantotestauksen tehokkuuteen.

Avainsanat: Kobotti, Lean, Tehokkuus

# Contents

## List of Abbreviations

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| ACC: | Aidon Customization Centre. Aidon’s production facility in which energy service devices are produced and assembled. |
| AMM: | Advanced metering management. A grid system created for the management of metering units. |
| Cobot: | Collaborative robot. A robot made to work along humans within a share workspace. |
| DMAIC: | Define, Measure, Analyse, Improve, Control. A Lean manufacturing methodology used in process improvement. |
| DSO: | Distribution system operator. Operator of an electrical distribution system that provides electricity to end-users. |
| ESD: | Electrostatic discharge. Refers to the abrupt and momentary flow of current between two objects with distinct charges. |
| FAT: | Factory Acceptance Test. A test or a process which a manufacturer performs before delivering a product to a customer. |
| HMI: | Human Machine Interface. An interface connecting a human to a machine or a system. |
| I-4.0: | Fourth Industrial Revolution. A term to describe the fast technological improvements made in the 21st century. |
| LTE-M: | Long-Term Evolution Machine Type Communication. A wide area network communication method with low power. |
| NB-IoT: | Narrowband Internet of Things. A wide area network communication method with low power. |

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| NVA: | Non-value adding. Actions in a process that add no value to a product. |
| PDCA: | Plan-do-check-act. A method part of DMAIC methodology. |
| P2P: | Point-to-point. A method of communication where two endpoints are directly connected to each other. |
| RF: | Radio Frequency. The oscillation rate of an electric or a magnetic field, ranging from 3 kHz – 300 GHz. |
| VA: | Value-adding. Actions in a process that add value to a product. |

# 1 Introduction

Collaborative robots are considered an integral part of the I-4.0, in which one of the many ideas is to increase automation. Traditional industrial robots are made to function in isolation, whereas collaborative robots are designed to work in the proximity of humans, often sharing a common workspace. Equipped with diverse sensors and vision systems, cobots can safely operate in that shared workspace. With collaborative robots, the aim is to enhance the work carried out by a human without the need to fully replace the human workload. In terms of production environments, cobots are an excellent fit to complete repetitive tasks which require the same exact output each time, such as in an assembly line. [1;2.]

This project was commissioned by Aidon Oy. Over the past two decades, the company has made a name for themselves as the leading supplier of best-in-class smart meters and grid solutions for energy distributors. A key feature of Aidon’s innovations is the move towards carbon-neutral systems which in turn demand the high-quality equipment offered by the company itself. The company was founded in 2004 by the initiative of a group of engineers in Jyväskylä, who predicted the need for the now well-known smart electrical grids. [3.]

The aim of this project was to enhance productivity and production testing of Aidon Customization Centre (ACC) located in Vantaa. The management, after extensive consideration, had concluded that in order to reach said goals, they would lean on the implementation of collaborative robotics. The decision was made with the mindset of utilizing future-proof techniques.

This thesis will look at the designing of a new production layout, in which the desired cobot-cell will be added in, as well as the testing of the cobot itself. With the optimization process, a part of the work is to also examine the possible wastes in the production. The safety aspect of the new cell will be considered according to the machinery directive. The end goal is to evaluate the gained efficiency in production as a result of the integration of the cobot-cell and the new layout.

# 2 About Aidon

## 2.1 Market

The company's sales are mainly focused on the Nordic countries, having offices in Finland, Norway, Sweden and Denmark, with the company's headquarters located in Jyväskylä. Aidon has already supplied well over 4.5 million energy service devices to over 120 separate distribution system operators (DSO's) whose main task is to guarantee end users uninterrupted supply of energy. Aidon's smart grid solutions, based on their advanced metering management (AMM), provide reliable support in this. [4.]

## 2.2 Energy Service Devices and Connectivity

Aidon Oy was the first company to include sensors to analyse received data from the electrical grid in their energy service devices. By doing so, the devices are able to register possible malfunctions in the grid in real-time, giving the chance for the DSO's to better understand the functionality of their own systems. All the smart energy service devices produced by Aidon are remotely operatable and upgradable.

Aidon has currently two different series of energy service devices in production, the 6000- and 7000 series, of which the 7000 series is the newer. Both have the same basic functionalities when it comes to measuring the consumption of electricity, with the 7000 series having extra features such as High-Speed Data Collection interface (HSDC) which allows it to have higher and more precise sampling capabilities. A 7000 series meter is shown in figure 1. [5.]

Figure 1. A 3-phase Aidon 7534 energy service device. [5.]

These energy service devices also divide into 1- and 3-phase meters which can be combined with several different communication modules, depending on the requirements and preferences of the client. Given the modular structure of the meters, the end users have a product which is easy to upgrade throughout the device's life cycle. Communication methods used by the modules are chosen in accordance with the environment the smart meters will be used in. Chosen communication method has a key role in the AMM system's performance. Aidon also offers a hybrid of the communication technologies in their products, for the best possible solution.

Aidon offers two different connectivity methods for their products: RF Mesh network and P2P. In the former solution, energy service devices connect to one another to create a mesh network which has an automated re-route capability. This network allows the slave devices to transmit data through each other, or even directly to the master. Aidon’s master devices operate in the 2G/4G network, communicating with the head-end system. RF mesh systems are suitable in environments where meters are placed in points not too far away from each other, allowing the mesh network to be created. In a P2P-solution the energy service devices are connected to the head-end system directly, using LTE-M / NB-IoT networks. The point-to-point solution is suitable for industrial environments, where the meters relatively far away from one another. [6.]

## 2.3 ACC Meter Production

The core work process in meter production at Aidon Customization Centre in Vantaa, excluding material gathering, generally consists of these work stages: testing and flashing of communication modules, labelling of modules, assembly of modules, assembly of module-meter combination, meter production testing, meter labelling, addition of meter terminal- and front cover, and finally the packing of the meters. The production work at ACC is built on work cards which include lists of required materials with their respective product codes as well as the needed software of the used slave/master modules in that work card.

The production work carried out at ACC Vantaa, happens on fixed workstations, or test lines, which will be discussed later on in the layout design. Ideally, there are three assembly operators working on a single test line at a time, of which one takes care of the steps leading up to the production testing, second operator handles the test phase and the third takes care of the packing steps. These roles change between work shifts, and possibly even during a single shift. However, at the beginning of the shift, all operators of the same workstation take part in the first steps, producing as many modules as possible, in order to get the entire meter production flowing adequately.

The production process on a test line starts with the testing and flashing of the communication modules, flashing referring to the uploading of a software. Flashing of the communication modules has thus far been performed manually using module tester units, commonly referred to as “flashers”. The testers have been programmed with LabView and they have dedicated HMIs created with the same program, allowing the assembly operators to select wanted software for the specific order as well as the overall viewing of the testing procedure. There are three module tester units in use at ACC Vantaa: marked T008, T009 and T012.

These testers can operate on four modules at a time. On average, the test procedure of four modules takes 15 seconds, but there are differences of a few seconds between module types. A module test unit with four modules placed in it can be seen in figure 2.

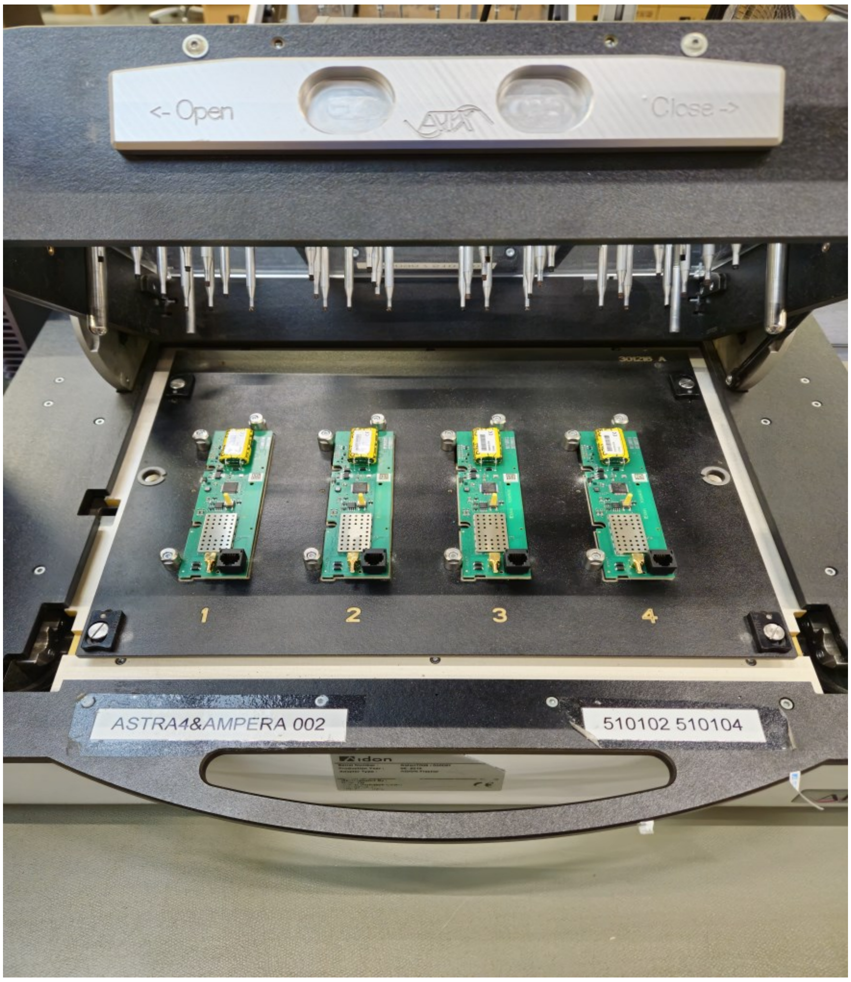

Figure 2. A module tester with four communication modules placed in it.

After the tester is done flashing the modules, an operator assembles the entire module, adding a front and back cover for the communications module. From there on the modules are attached to the actual meter unit and moved forward to be tested.

Once the module has been connected to the meter unit, an operator moves it on to production testing. During this phase, its general functionalities are tested, and certain parts are added to its software, and the meter will be equipped with a label corresponding to the client’s specifications. Having passed the testing successfully, a seal will be added to the meter, and it gets moved to packing.

The meters at ACC Vantaa are packed into boxes of 10, with regards to both 1- and 3-phased meters. These boxes are then equipped with a product sticker and loaded onto a pallet which are limited to hold 20 boxes when using 3-phase meters, and 28 boxes when using 1-phase meters. A finished pallet is then labelled with a copy of the work card that it was made according to, and moved to the outgoing deliveries section where they are forwarded to shipment. The focus of this project is only on the process in the production phase.

# 3 Lean Manufacturing

## 3.1 Philosophy and Origin

Lean can be thought of as a way to work and carry out tasks, by reducing waste and linearizing processes. According to its principles, the use of resources in any other part of the process, other than the value adding phases, is considered a waste, with the end goal being the cutting of that waste. The value of a product can be determined by considering what the customer would want to pay for. In short, Lean methods aim to maximize value of a product or a service with the least amount of work put in. Lean principles include things such as value-adding principles, which consist of steps that add value to the product or service, and non-value adding principles, which take a look at steps that are considered a waste. Value-enabling principles, which allow the value-adding steps to be done more efficiently, are also a part of Lean principles.

Lean and its principles are widely considered to have originated from Japan’s manufacturing industry, and more specifically, from the automotive industry. The term itself was first used by Bob Hartman in an article from 1988, “Triumph of the Lean production system”. The main originator of the Lean system is considered to be the Japanese automotive company, Toyota. The Toyota Production System, or TPS, is the system that we now consider to be the prime example of a production process which implements Lean. [7;8.]

## 3.2 Six Sigma

Compared to traditional Lean manufacturing, Six Sigma methods are focused on the customer’s specifications in business processes: the reduction of variation and defects in manufacturing and services, with the aid of enhanced data acquisition. Nonetheless, as with Lean manufacturing, Six Sigma aims to continuously improve used processes. Lean manufacturing often gets combined with Six Sigma in project conduction, so that these projects will look at production problems in as vast detail as possible, approaching the problem of time wasted (Lean), and the material waste and variation (Six Sigma). These problems are highly intertwined. [7.]

## 3.3 DMAIC Methodology

Lean Six Sigma is carried out as projects, and these rely on different methodologies such as DMAIC, which can be thought of as a data-driven method for the improvement of business processes. This method consists of several different statistical tools that help with the optimization of processes. As the name suggests, DMAIC has five different steps, which can be seen in figure 3. [9;10.]

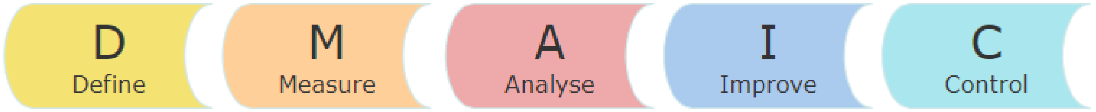

Figure 3. Graphical representation of the abbreviated words of DMAIC.

The first step is Define. In this step the aim is to define the targeted problem in as much detail as possible. It needs to be clear which part of a process needs improvement. In order to do this, you need a clear objective you want to achieve.

The second step of DMAIC is Measure. The purpose of this step is to collect data and create a baseline of the whole process which, in the end, can be compared to the output of the improved service or process, and thus determine whether the improvement yielded better results than the old process. High quality data has a key role in the DMAIC method.

Analyse is the third step of this method. In this, the goal is to analyse the measured data to create an understanding of where the improvements could be made. It is also essential to recognise the root causes of the found problems, which can be quite complex. However, tools have been created for such complex analysis.

The fourth step in DMAIC is the Improve step. This step consists of the identification and implementation of a solution. The Improve step requires creativity to come up with solutions that were not previously thought of. Nevertheless, the solution can also sometimes be quite a simple one. A method commonly used in this step is classic brainstorming. Often, the simplest and easiest solution is the best. During the improvement step, the goal is to get rid of the key root causes of wastes and identified problems. A part of this step is also the testing of the found solution using a method called PDCA, or plan-do-check-act. It is also advised to create a detailed plan for implementation.

The final step in this method refers to the Control step, in which the core aim is to finalize the made changes in the process and make sure the implemented changes are sustained correctly. In this step the improvements are tracked and verified. [9;10.]

## 3.4 Kanban

The method of Kanban originates from the same source as Lean manufacturing itself, the Toyota Production System. It is a way of visually managing production and workflow in the customer demand-oriented system. It also goes by the name of Just-in-time production. As the name suggests, the aim is to produce the goods, not into buffers, but according to demand to utilize inventory space as optimally as possible. The system created by Toyota is a “pull” system, meaning that in production, such as in an assembly process, downstream processes “pull” a product from a previous process on to the next one and so on. The Kanban cards can be used in this “pull” system to indicate the amount and type of a product created in said previous processes. The amount of a specified product that will be created in a process is dependent on the incoming requests, i.e. orders. The cards move along the entire process until it is finished. This allows for an accurate tracking of production and the limiting of work in process, or WIP, orders in an inventory. Kanban alleviates managing the work- and material flow. [11;12.]

## 3.5 Lean Layout

When considering the effectiveness and productivity of a facility, a key role is attached to its layout. A well-designed layout will in and of itself yield great results to a company. Lean methods and philosophies are often used in designing a layout. In essence, a layout looks at the physical placement of available resources in a facility. Optimizing the space usage is in an important role of a layout design process, especially in cases where the available space is limited. A layout which ensures a good flow of material and equipment at the lowest possible cost, is considered ideal. Making everything more productive (e.g., workflow and workers) is where layout design and Lean manufacturing merge. When designing the layout of facility, one should also take into consideration the following items:

- Promoting safety of both workers and equipment.
- Minimizing the distance traversed for materials.
- Maximizing flexibility of processes.
- Facilitate changes and extensions.
- Get familiar with the work process to create a better understanding of what is needed of the layout.
- Get input from the actual workers.
- Flow of information is also critical.

Ultimately, a desired layout should be planned out in sufficient detail before implementation to avoid unwanted surprises. [13;14.]

# 4 Hardware and Software

## 4.1 Hardware Introduction

The addition of the new cell brings about new hardware to the facility which was not previously in use, such as the cobot itself, a desk tailored for this specific application and tailored ESD protected boxes for the flashed modules. An integral part of the new cell is also the previously mentioned module tester, as the cobot’s main responsibility lies in the enhancement of the module production. All the locations for the different components on the cell’s desk have been predetermined, lessening the chance of error. The cell can easily be moved around due to its design and lack of limitations in transportation. An illustration of the new cell can be seen in figure 4, with the cobot in the top centre, a module box to the left of it, the two ESD protected boxes below it, and the tester unit to the right of the cobot.

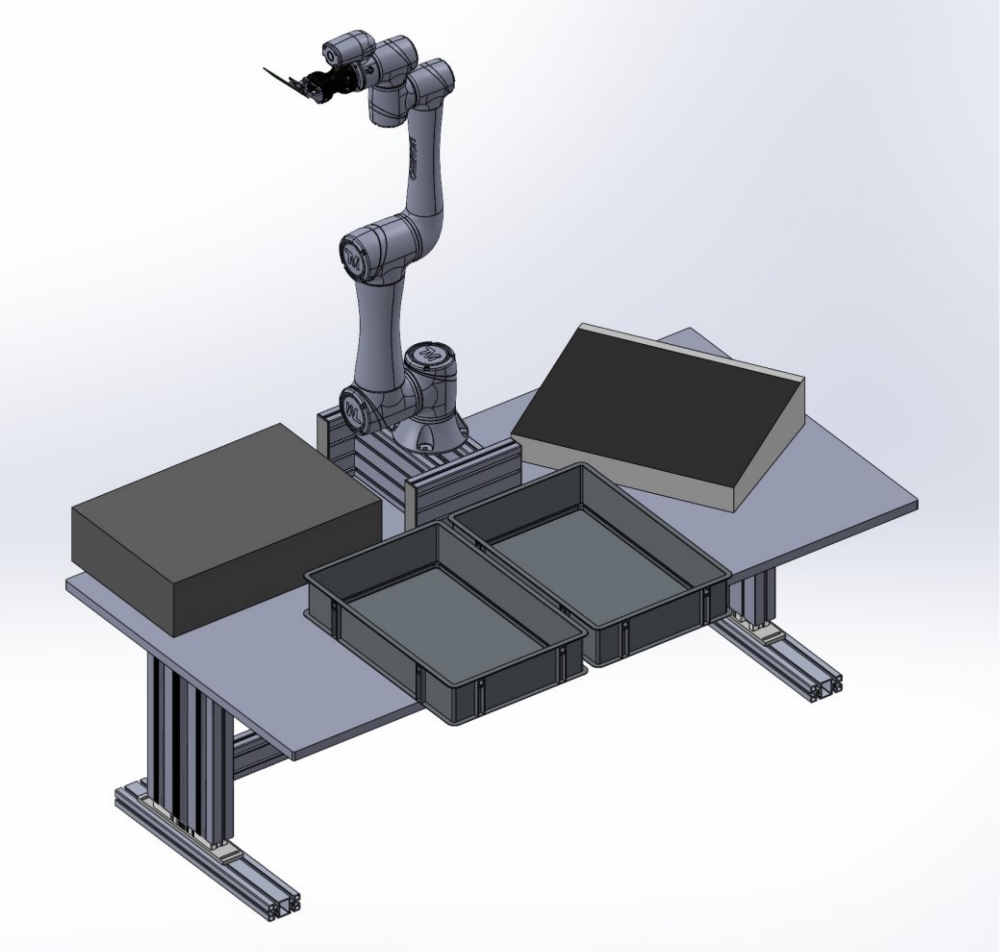

Figure 4. An illustration of the new cell with its different components.

### 4.1.1 Omron TM5-900

TM5-900 is a 6-jointed cobot, weighing 22.6 kilograms. Its maximum payload is 4 kg, with a maximum reach of 900 mm. Average speed of the cobot is 1.4 m/s. It can be mounted on several different surfaces and components such as tables, walls and on mobile robots. The cobot used in this project is manufactured by OMRON, and the software design for this specific application will be carried out by OiTec Oy. TM5-900 is a collaborative robot designed to work safely and fluidly with humans in a shared workplace. It has a built-in machine vision system enabling visual control and precise inspections/measurements, making the cobot highly capable at error detection. The cobot is shown in figure 5, with the used gripper tool attached to it. [15.]

Figure 5. An Omron TM5-900 collaborative robot.

TM5-900 can also be equipped with optional components related to safety and functionality, such as a safety laser scanner and a light curtain, both of which can enhance the rate at which the cobot functions.

The aim is to reach a production speed of 120 modules per hour for the cobot in its collaborative-mode before the Factory Acceptance Test (FAT).

### 4.1.2 Gripper Tool

The gripper tool used on the cobot is an adaptive gripper Hand-E, manufactured by Robotiq. Hand-E gripper weighs 1 kg, and it has the capability to handle payloads up to 4.7 kg. Ideal work tasks for the gripper include assembly and pick & place. Hand-E has a reach of 50 mm, but it can be adjusted if need be. The gripper’s closing speed can be adjusted to anywhere between 20 and 150 mm/s. [16.]

### 4.1.3 Cobot-Cell Desk

As mentioned above, the table has been modified so that all the components of the new cell will be on their specified locations, due to the requirements of the software that will be implemented. It will have height adjustable legs, giving the possibility of finding the optimal solution. The desk plate will have a depth of 900 mm, with the width being 1900mm. The desk has been fitted with a 180 mm high mount for the cobot, giving it a better range of motion over the whole station it operates on.

### 4.2 Software

The layout of the facilities at ACC Vantaa have been created with Microsoft Visio, although some parts of the floor plan, such as the general surrounding structures (walls, windows etc.), have been made with a separate CAD-software. Mainly the production and warehouse areas have been planned with Visio. It is primarily made for creating varying diagrams such as floor plans and flowcharts, as well as countless other types of graphical presentations. The software comes very handy in this project, as it can layer several drawings on top of each other, allowing for fluent changes to be made quickly. [17.]

## 5 Scope of the Research

As mentioned, the focus of this thesis project was on designing a new layout for the production of ACC Vantaa, with the integration of the new cobot-cell to improve production testing capabilities.

Regarding the project, regular meetings with the management were held to track progress and discuss possible changes. Workers from the production team were also included in the discussion, with their opinions and suggestions in areas of improvement taken into account when implementing changes. Designing the new layout, Lean methods such as DMAIC and Kanban were considered. Although the addition of the new cell into the old layout was the main focus, the aim was to also look at areas in which cutting down waste was possible. Therefore, each section of production was looked at individually to determine if there was a possibility for improvement.

Each part of the production process was timed individually to create a baseline for the efficiency and throughput time of the entire production process. Due to the number of different products, the most produced product at the moment was taken into consideration during the baseline creation. Furthermore, an average production rate of a day and a week was researched to create a comparison between the old production process and the new, with the introduction of the new cell.

## 6 Old Production Layout

Aidon Customization Centre Vantaa consists of roughly two sections, excluding the office and meeting rooms: production area and warehouse. These two areas are separated from each other by the transportation hallways. The area of ACC’s production and warehouse is roughly 900 $m^2$, of which the production area alone takes about 160 $m^2$. The production layout has gone through several changes over the years, in the pursuit of finding the optimal setting for the maximum production. The warehouse area surrounds the production area. As the goal of this project was solely to enhance production with the addition of the new cell as well as general changes made to the production layout, the shown figures will only look at the production area itself, as well as some parts of the transportation hallways and the dispatch area. The old production layout can be seen in figure 6.

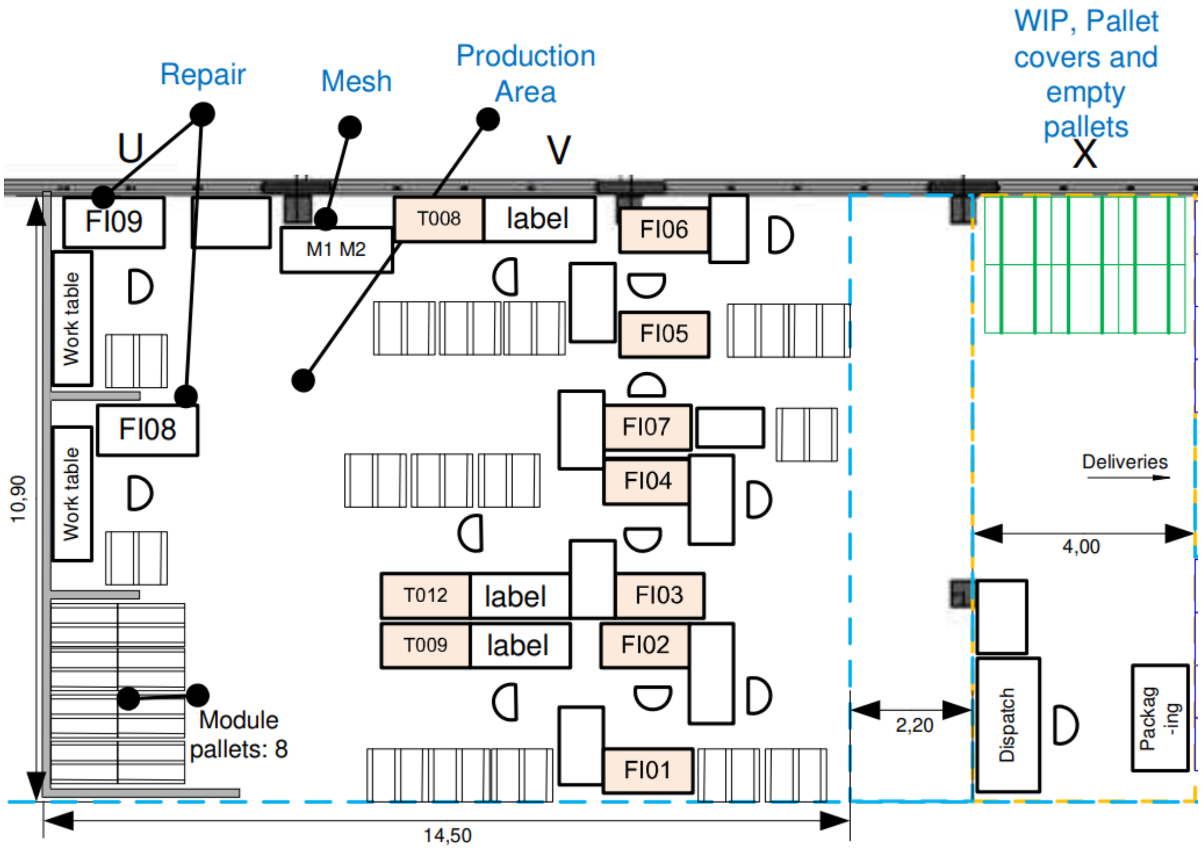

Figure 6. Old production layout of ACC Vantaa.

## 6.1 Test Lines

The old production layout has four test lines (7 meter test benches) which include all the phases required for meter production. The in-detail meter production process at ACC Vantaa has been explained in chapter 2.3. These test lines have been oriented in a way that the process flow, such as in the figure above, is from left to right, starting off with the module production, moving into testing, and ending with the packing of products. The packing areas have a direct line to the deliveries warehouse. Three of these test lines function in the same fashion (FI01-FI02, FI03-FI04 and FI05-FI06). Each of these three test lines have two test benches. However, test line FI07, which has no module production within it, has been fitted into the production for smaller orders that can be handled by a single operator. Moreover, it can also function as an additional workstation for the other test lines if need be. ACC also has a separate MeshNet production cell, which has a very limited use. An illustration of one of the three test lines can be seen in figure 7.

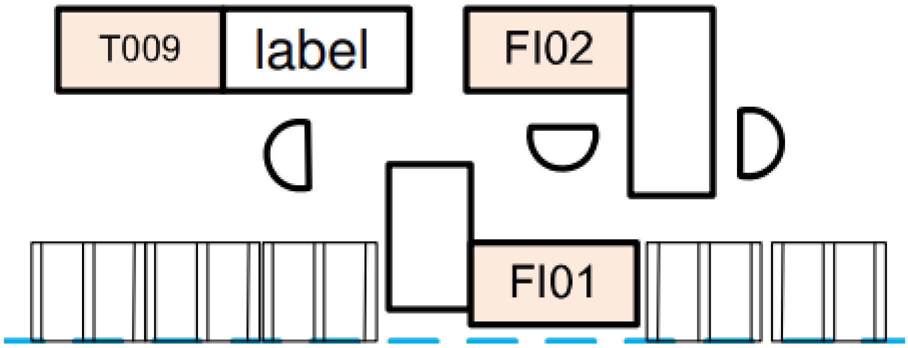

Figure 7. A test line with its module production, meter test benches and packing.

## 6.2 Repair Area

In the old production layout, there is two separate repair cells for which two repair workers were allocated. Broken material handling, customer returns and certain test cases were some of the functions of the repair cells. Both repair cells have test benches to perform required tasks. Not long ago, a third repair cell was in use, however, it was since replaced by a small storage for modules, capable of housing 8 pallets with 36 boxes on each. The repair area including the small module storage can be seen in the figure below.

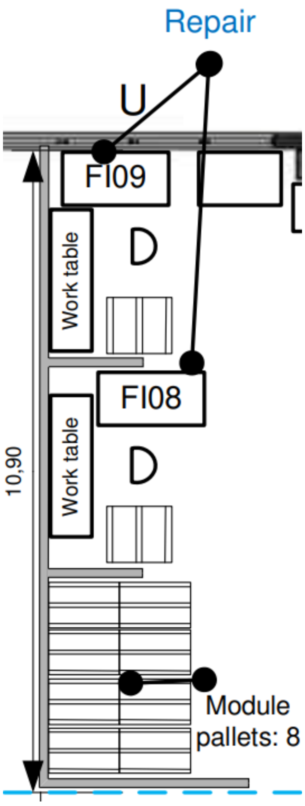

Figure 8. Repair stations and quick-access module storage.

Due to the lack of sufficient space at ACC Vantaa, a decision was made to move at least a portion of the repair department to an external service provider’s facilities. In the beginning, the idea was to only move the repair station FI08 and keep FI09 for certain occasions. However, during one of the meetings regarding the ongoing project, it was concluded that repair station FI09 could also be removed if necessary. Another option was the relocation of the repair stations within ACC’s facilities. The area taken by the repair stations and the small storage in the old layout is roughly 30 $m^2$, meaning nearly one fifth of the entire production area.

## 7 New Production Layout

The main issue of the old production layout was related to space. The old layout would not have been able to house the new cobot-cell without creating obstructions and problems with the workflow. As the repair stations would be removed, the space they host could be used for the new cobot-cell or in other productive ways. Relevant material should have space within the production area, to cut down the distances traversed in order to collect order specific materials, thus lessening the time used on non-value adding (NVA) actions, while maximizing the value-adding (VA) time.

## 7.1 Two Plans

Going into designing the new layout, and considering the integration of the new cell, two ideas were initially taken into closer inspection. The first one being the creation of a high-capacity production line. The idea was to integrate the cobot-cell into an existing test line to create a mass-producing line. In this configuration, more resources (both operators and materials) and space would be allocated to the chosen test line to accommodate for the higher testing capacity. This would also mean that the need to share bigger orders between separate test lines, would be nullified, which for error detection is favourable.

The second plan consisted of a centralized module production, in which the idea is to create a mass-production cell for modules, for which a form of Kanban system would be implemented. The modules would be produced to buffers, or supermarkets, from where operators of the test cells would gather the produced modules corresponding to the requirements of their chosen work cards (work cards explained in chapter 2.3).

## 7.2 High-Capacity Test Line

One of the ideas for the production layout came from the suggestion that a high-capacity production test line would be created. In such a test line, the main task would be to handle bigger orders (upwards of 500-800 pcs), and to house more operators on it. It was considered that a 4-operator test line would be attempted to implement allowing for a continuous production of modules, which has mostly been the slowing factor in production.

A key part of this test line would then be the integration of the new cobot-cell, which alone would handle the entire module testing procedure of that test line, allowing an operator to work on other phases of the production. Like before, the optimal location for the module testing procedure to take place, would be at the very beginning of the designed test line. The first draft of a high-capacity test line can be seen in figure 9.

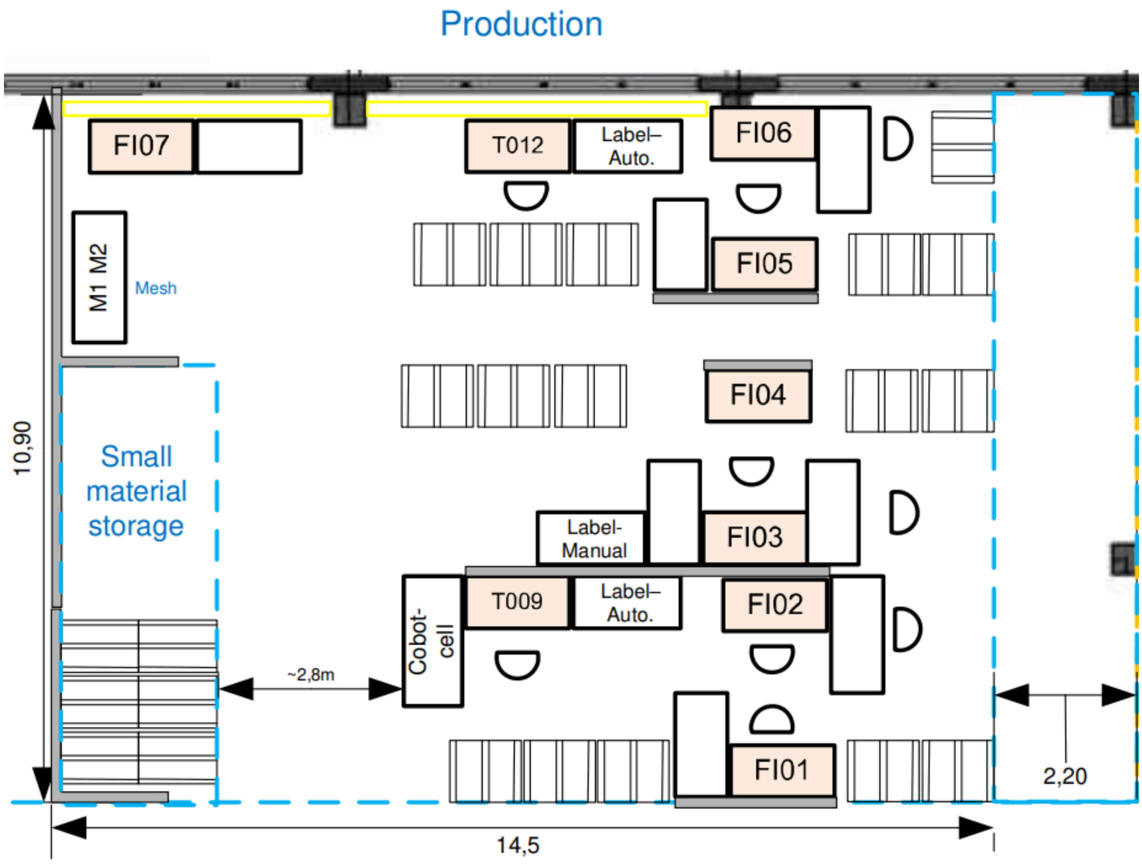

Figure 9. First draft of a high-capacity test line within production.

While designing the new production layout, a decision was made to remove both repair stations from the production area, due to their lack of utilization currently. As mentioned above, these stations will be partially relocated to separate facilities. These stations release plenty of space for more valuable use.

The small module storage in the old layout was implemented for when a time of component shortage was taking place, to keep better track of available modules. Since the communication modules are, even in normal operation, gathered by the box within the production area, the pallets of modules could then be moved back to the surrounding warehouse. With this, it is possible to free space for other relevant material, such as module covers etc., which are more commonly transported by the pallet. The small material storage was also extended over the previous location of one of the repair stations, to host an additional quantity of relevant materials. The benefit being the decrease in used time for non-value adding actions.

The new cobot-cell was now fitted into the production layout. One of the ideas centred around a high-capacity test line, thus the new cell was placed into the first test line. In addition to the new cell's module tester unit, another unit would be placed into the test line, which in turn would be operated manually by an operator. This high-capacity test line would also be occupied by four assembly operators, two of which would handle meter production testing, allowing for a higher rate of production. Therefore, one operator would be assigned to packing and another to module production and assembly.

The integration of the new cell requires additional floorspace to accommodate for safety aspects as well as efficiency. The space can be acquired by moving each of the test lines in production, to widen the newly introduced one. Thus, moving test bench FI07 would be necessary in the first draft. FI07 and the MeshNet test station would be relocated to a unit of their own.

Feedback was gathered from the management and production workers regarding the proposed layout plan. The high-capacity test line would not be fitted with another module tester unit since it was thought that the cobot alone could produce the required number of modules, allowing the higher production rate. Thus, module tester unit T009 would be moved back to test line FI03-FI04. The management expressed their willingness to keep test line FI07 closer to its original location. However, due to the added space to test line FI01-FI02, it could not be returned to its original location, but it was also considered that it could be merged with test line FI05-FI06. The second draft of the high-capacity test line idea can be seen in figure 10.

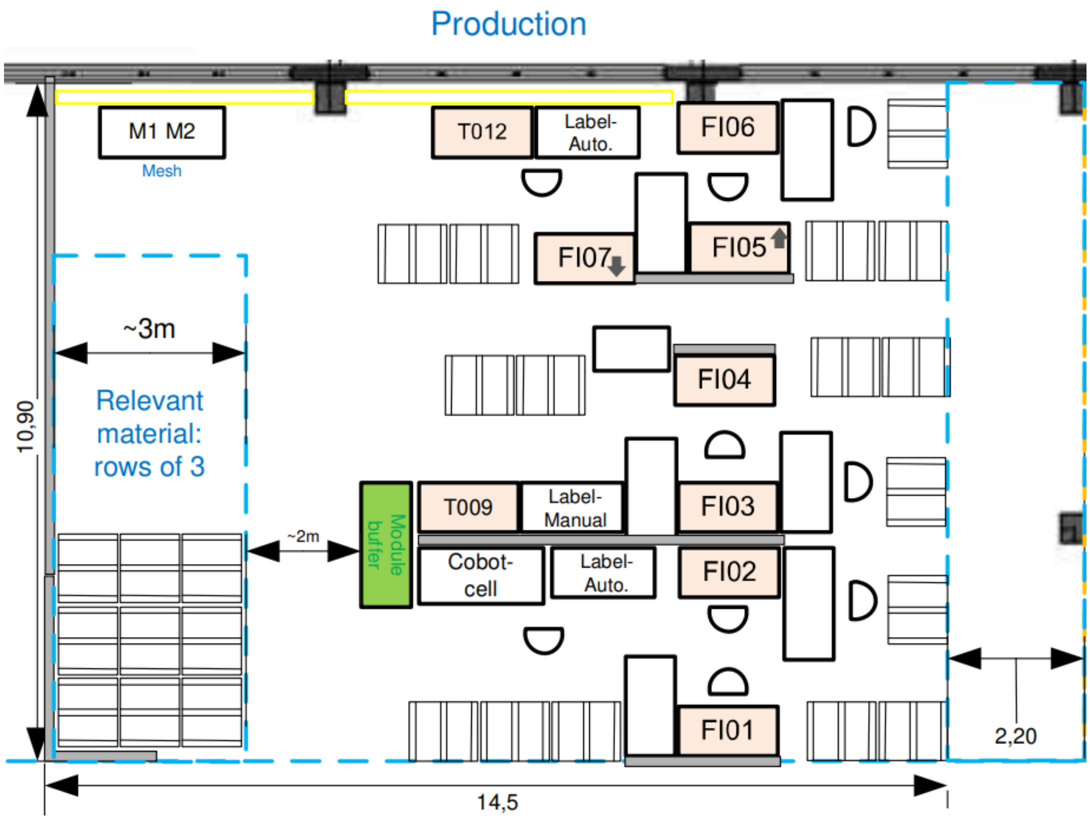

Figure 10. Second draft of a high-capacity test line within ACC production.

The second draft of the new layout includes suggestions made on the basis of the previous layout. In this layout, the high-capacity test line now follows a more linear model, having moved the additional manually operated module tester unit back to its original location on the test line. A slight change was made to the orientation of the MeshNet-station as well. This layout plan was also fitted with a module buffer that would be integrated to the surrounding area of the cobot-cell. Test bench FI07 was moved back closer to its original location, merging it to test line FI05-06. The storage for relevant material was also enlarged to fit rows of three pallets along the previously designed small material storage.

During the development of the cobot’s program and the pre-FAT, it was noticed that it would not reach the targeted operating speed of 120 units/h in its collaborative-mode, where no extra safety equipment would be necessary and where the cobot-cell could seamlessly be integrated into a test line. It was then deemed that the cobot would have to be operated above the limitations set by the collaborative-mode, to reach the wanted output. The need to increase its operating speed forced a new risk assessment to be made, in which it was noted that the new cell would require additional safety measures, such as additional floorspace.

In light of these new findings, the cobot-cell could not be fitted into the wanted test line without disrupting the production process. Therefore, a decision was made to move away from the idea of a high-capacity test line.

## 7.3 Separate Module Production

As mentioned above, one of the ideas consisted of a layout where a separate module production cell would be introduced into the existing layout. The key part for this configuration is the utilization of the cobot-cell. Having other parts of the assembly and testing processes be close to the added cell, the cobot is constantly with an operator in close proximity. Thus, an efficient material flow and a possibility to quickly resolve issues can be upheld. This would lead to the current test lines being broken apart from their current configurations. An illustration of the new layout with a separate module production cell, can be seen in figure 11.

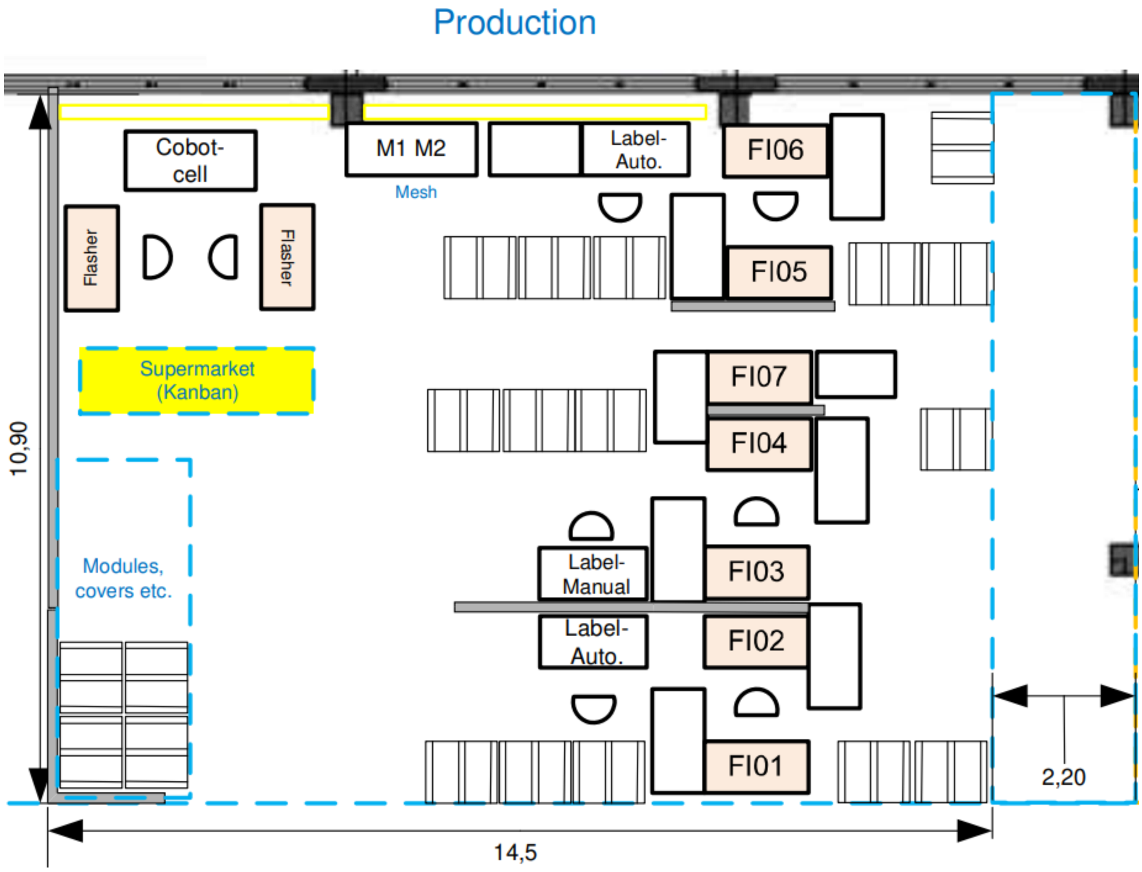

Figure 11. First draft of the new production layout, with a separate module production.

The aim in this layout is to utilize the space left by the removed repair fixes to host a centralized module production cell. Considerable changes also relate to the addition of a small material warehouse within the production area itself, allowing for shorter distances in material gathering, decreasing the NVA time. This area would hold relevant (most used) material. In this configuration, each test bench would remain in the old position, since it was determined that their location is already optimal, given the direction of the production flow (towards the deliveries).

With this layout design, a supermarket would be introduced into the production, and a form of Kanban would be used in this scenario. In general, two operators would be allocated for the module production, each operating a single module tester, while also monitoring and operating the cobot when necessary. Only the testing of communication modules would be performed in this production cell, while the rest of the production process in the remaining test lines. These operators would produce modules according to the current customer demand, and then move them to the supermarket with a specific Kanban card attached/linked to that batch, indicating the module product code and the software flashed on it. These modules would then be picked up by test line operators according to their work cards for further use.

Although the cobot is meant to be used in proximity of the production operators, the previously mentioned pre-FAT indicated that the designed cobot-cell needed to be allocated more space within the production layout: by giving it enough floor space around it, we can decrease the likelihood of collisions and other safety hazards. Moreover, a collaborative workspace needs to be designed in a way that an operator can safely perform all tasks around it without the risk of additional hazards. Safety fences should be taken into consideration under the machinery directive. [18.]

Having proposed this draft of the new layout, feedback was gained from the management and production workers. It was determined that creating a separate module production cell would be inefficient. Although the larger relevant material storage would decrease the non-value adding time in material gathering, the extra steps to deliver material to the test lines (i.e., transporting material between module production and test lines) would, on the other hand, increase it. When considering Lean manufacturing, one of the key elements is the linearization of processes [8]. Therefore, disconnecting the module production of each test line to a separate one could be considered unbeneficial, especially in the case of an assembly process. However, the cobot-cell needs to be kept separate from the rest of the production test lines, due to safety requirements which were brought to attention during the risk assessment.

During the layout design process, it was brought to my attention that a new test area would be needed at ACC for the introduction of a new product. Therefore, further changes to the layout needed to be considered. An illustration of the production layout with the above-mentioned changes can be seen in figure 12.

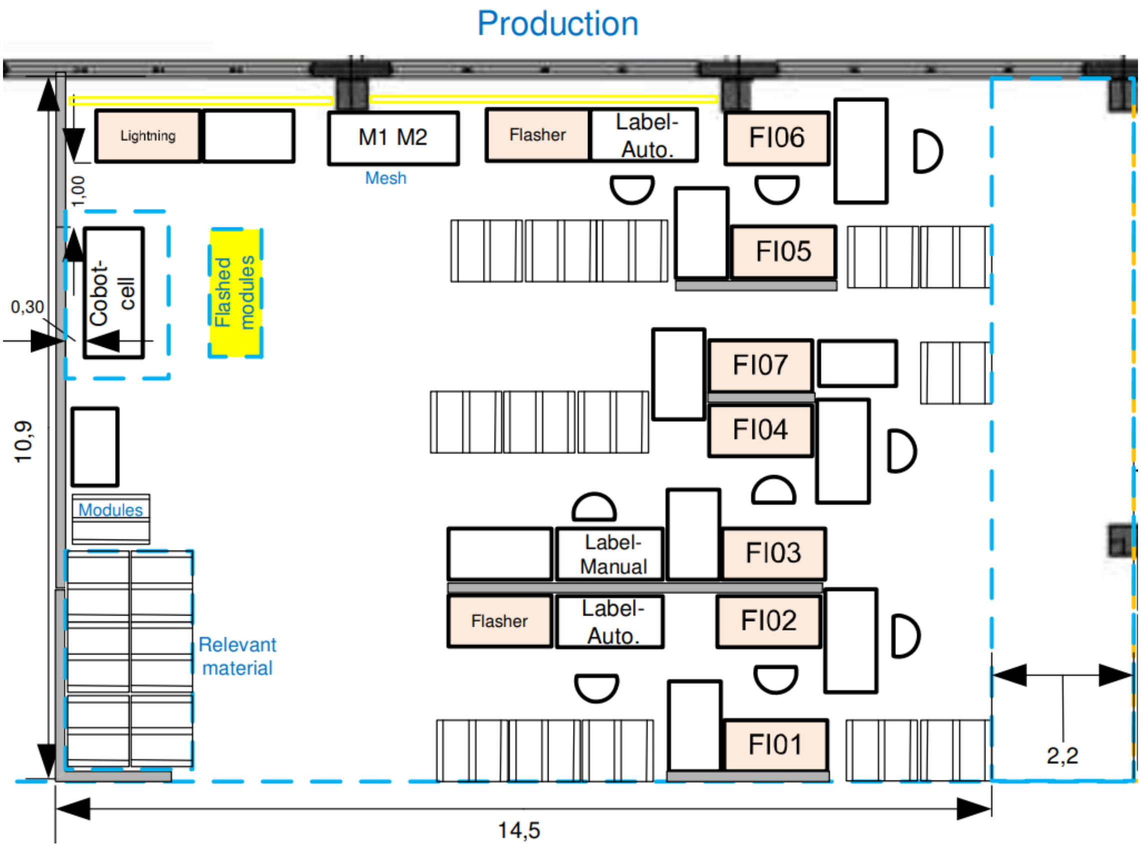

Figure 12. The final draft of the production layout.

The changes in the final draft above include the returning of module tester units, or flashers, back to test lines FI01-02 and FI05-06, as well as the illustration of the reserved space for the new test line to be introduced, in this draft marked as “Lightning”. It is somewhat unclear as to how much floorspace the new test line will be needing, however, due to the mobility of the cobot-cell, the space acquired from the repair stations, and the layout changes, fitting the new test line will not be an issue according to the management. The storage for relevant materials will have pallets in a 2 by 3 configuration.

The location of the cobot-cell in production is on the back wall, so if protection is needed, such as safety fences etc., only the other three sides need to be protected. Space was left for a pallet of modules next to the cobot-cell for a better material flow. A module buffer has been fitted into the layout plan next to the added cell, for which a shelf, or the likes of, will be used. Due to results in the FAT, the implemented cell will possibly be fitted with safety fences.

# 8 Implementation and Results

## 8.1 Layout Plan

Implementing all the designed changes started off with clearing the area that would be used for the new cobot-cell as well as other added equipment surrounding it. As mentioned above, the repair stations would make way for the introduction of these changes, and the partial relocation of these stations to an external service provider's facilities commenced. However, as mentioned in the layout design chapters, part of the repair actions would still be performed at ACC. Therefore, during the clearing of their previous location, a new area was designated for them close to the server room and next to the shelf marked as "P". The functions of the remaining repair stations will not be discussed further, given that it is not crucial to the rest of the project.

As a significant part of the old production layout went unchanged, the implementation of the new changes went smoothly. However, during the delivery of the new cell, it became evident that an additional workstation would be needed for the control panels and other equipment. In the end, it posed no relevant issue due to the sufficient acquired space from the layout changes. Also, a workstation left by the previous repair stations was utilized for this purpose. The workstation hosts the HMI of the cobot as well as the module tester's own PC and HMI.

A part of the layout changes included the introduction of a small material storage within the production area to house material relevant to the current production needs, such as module covers and meters. The idea being the linearization of the production process as well as the elimination of waste in transporting materials. Moreover, the idea was to move the current module pallets from said area to the main warehouse due to the nature of their transportation quantities to the production process (a box at a time). However, having tested this idea, it was determined that the total gain from this change was not significant enough, when considering amounts above a pallet of finished products, for it to be implemented in the end: having these relevant materials in the production area does reduce the amount of the total NVA time but moving the module pallets to the main warehouse, on the other hand, increases it. Furthermore, these boxes of modules need to be gathered more frequently since these boxes only contain 140 modules at most, while pallets of meters, covers and other relevant materials come in quantities of over 200 units. Figure 13 below shows the difference between the original production processing time and the processing time with the suggested idea, using 10 finished units as a reference.

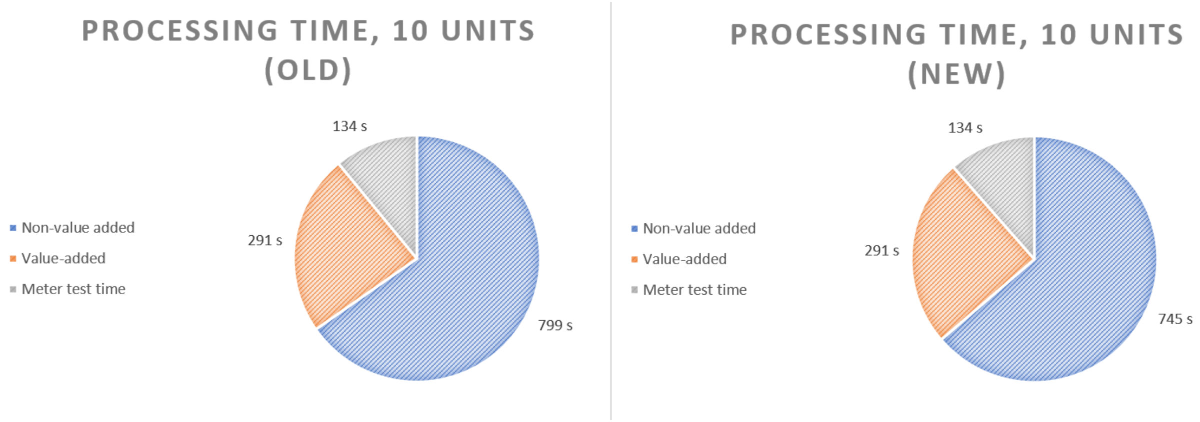

Figure 13. Processing times for 10 units, with and without a small material storage within the production area.

The old production has a total processing time, or throughput time, of 1224 seconds, while the newer one has a throughput time of 1170 seconds. Using 10 units as a reference, the introduction of a small material storage within the production area would result in a 4.4% decrease in throughput time. This gained efficiency could be considered valuable, however, the scale at which ESD's are produced at ACC Vantaa, using 10 units as a reference is not up to scale. In the figure below, 200 units of finished products was used as a reference, to show more comprehensive results for the throughput time.

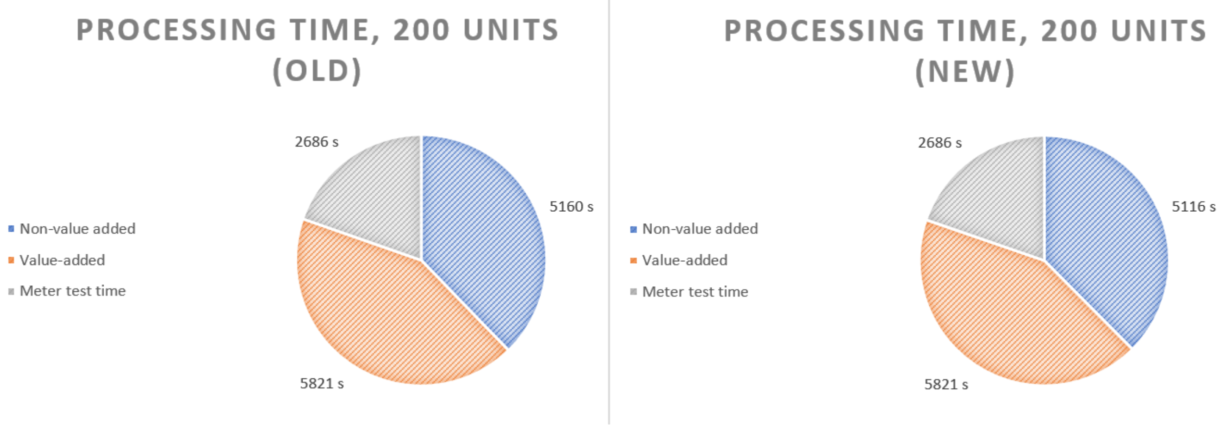

Figure 14. Processing times for 200 units, with and without a small material storage within the production area.

With a reference of 200 finished units, the throughput times of the old and the layout with a material storage in the production area are, respectively, 13 666 seconds and 13 623 seconds. Therefore, we see only a decrease of around 0.3% when considering the total throughput time of 200 units. As mentioned above, this result is not significant enough to implement the small material storage within the production area.

As concerns the successfulness of the layout design, considering the recommendations of a Lean layout is useful. The focus of this project's layout design was, first and foremost, to create sufficient space for the utilization of the new cobot-cell. Measures, such as removing the repair stations from the production area, were taken. The goal was also to achieve a layout which was flexible if other changes/implementations needed to be made. Therefore, the designed layout was successfully planned: space was reserved for an up-and-coming product's production line, and with the cobot-cell's placement, additional floorspace was gained for the rest of the production, making material handling easier within it. The safety aspect of the new layout was also a key part of its design. With the changes made, the safety of the workers has been ensured, and no unnecessary health hazards should be expected. Having also no significant changes to the process of the old test lines, getting the assembly operators used to the new layout will not be taking long, ensuring the production’s efficiency throughout the changes.

DMAIC methodology was closely utilized in this application: measurements were made of the original process to create a baseline for the new changes, these measurements were then analysed to create a better understanding of where changes could be made, and finally the improvement plan was implemented to the original production process. Following the final step of the DMAIC methodology, it was made sure that the implemented changes were sustained, and all of it was followed through.

## 8.2 Cobot Deployment

Deploying the cobot was carried out during a two-week period, right after its delivery. During these weeks, fine tuning of the cobot’s final process cycle was done as well as the overall testing. The initial goal was to have the cobot perform module testing on two separate module variants, and two different module box types. In future, the aim will be for the cobot to perform testing on all possible variants from Aidon’s selection.

The numbers discussed in this chapter only look at a set of data from a short period of time, namely the two-week testing period, due to several delays during the project. The original goal for the cobot’s testing capabilities was 120 modules per hour, using its cobot-mode, and around 150-160 modules per hour, using its partial cobot-mode, or SF9. Using the data acquired during the testing period, the actual results of the cobot, and the average of the original production process from a three-month period, can be seen in table 1.

Table 1. Production rates for the cobot’s different modes, and the original production process of a three-month period.

| **Method** | **Production (units/h)** | **Production (units/shift)** | **Production (units/month)** |
|---|---|---|---|
| Cobot-mode | ~ 96 | 672 | 29 568 |
| SF9 | ~ 116 | 812 | 35 728 |
| Original process | ~ 150 | 1200 | 52 976 |

As mentioned, the shown numbers are rough estimates and averages that could be expected. A 7-hour time frame was used for the cobot to account for time used for material handling and troubleshooting. It should also be noted that the given results of the cobot in its different modes has been calculated in a way that the cobot makes 0-4 errors in gathering the modules.

ACC Vantaa has currently three module flashing stations. Therefore, the average production rate of a single flasher in a month would amount to 17 658 units. In its collaborative mode, the cobot would then have a gained efficiency of 67%, and in its SF9-mode, a gained efficiency of 102%, on a single flasher.

Using the SF9-mode of the cobot requires additional safety measures, such as safety fencing. Thus, it will mainly be used in its collaborative mode for now, allowing for the possibility of a 22% gain in efficiency in the overall production process. Due to the nature of the cobot’s operation, the cobot would be best used in producing modules to a buffer.

During the deployment of the new cell, the workers and management were also trained and guided in using the cobot safely and efficiently. Using the cobot is fairly straightforward. Therefore, the training did not take long and its implementation into production was smooth. Due to the lack of sufficient time in testing, getting valid data for the profitability assessment was not possible in this thesis project.

# 9 Future Improvements

During the implementation phase of the project, it became clear that other improvements could be made to the overall production process. However, these improvements would not be necessary over a short period of time but rather could be considered in the future.

There are currently three separate module labelling machined in use at ACC Vantaa, two of which are automated, and one being manually operated to an extent. When considering the overall efficiency of the production process, it would be recommended that another automated labelling machine would be acquired. This would also improve the consistency in applying labels to the module covers.

Currently the most slow-moving phase of the cobot's process is the material feeding, as well as the cobot's process of picking the new modules. The boxes of modules are placed on the cell's desk by hand, while also making sure that the modules are well placed within the box, requiring the most time out of the entire process. The modules could be fed to the cell on a conveyor system, making the pick-and-place operation of the cobot easier. A system which could accommodate several hundred modules, compared to the original boxes' 88 and 140. With an automated feeding system, overnight production would also then be possible. If the current cobot-cell turns out to be productive and profitable enough, another similar cell should be acquired.

During the deployment of the cobot, another part of its process that could be sped up, was noted. The opening and closing of the flasher unit is currently done manually, with the help of gas springs. To make the cobot even more efficient, the opening and closing of the flasher could be automated using a pneumatic system. This would save time in the process cycle because the cobot currently opens and closes the flasher hatch quite carefully, so as to not overload the gas springs, making them wear off quicker.

Aidon, in their production at ACC Vantaa, uses cardboard boxes for the modules, and these boxes are recycled multiple times. Often, these boxes are in a bad condition, which in the old production process is not necessarily a problem, however, the cobot can sometimes struggle to pick up a module from said boxes due to the unpredictable orientation of a module. It was discussed with the management, that replacing the cardboard boxes with ESD protected boxes, which are used in the cell's module placement process, would benefit the overall consistency of the cobot's operation. Moreover, having these newer boxes would protect the modules even better.

# 10 Conclusion

Collaborative robotics is increasingly tied to today's industrial world. Their ability to enhance processes cannot be overlooked. However, implementing these machines need good planning. Having the ability to enhance any process, while making a humans work easier, is clearly, advantageous.

The aim of this project was to help Aidon Oy to enhance their production capabilities, with the aid of collaborative robotics. It was noted that a part of their production process at Aidon Customization Centre Vantaa, due to its repetitive nature, could be performed with collaborative robotics.

The main task of this thesis project was to design a new production layout for ACC Vantaa, where the desired cobot-cell could be introduced. Part of this thesis also took a look at the deployment of the said cobot-cell. Since, in its core, this thesis project aimed to enhance and optimize the old process, Lean Six Sigma philosophy and methods were taken into closer inspection, such as DMAIC methodology. The old process was researched to create a baseline, and a point of comparison for the newer production process.

The new layout was implemented and the cobot deployed successfully into the production. The new changes centred around the introduction of the new cobot-cell. In this thesis project, it was deducted that the old production process was already functioning highly optimally. Thus, no significant changes were made to that process. Due to the limited time in deploying the cobot, only estimates of its efficiency were made, and according to these estimates, the entire production process would see a 22% gain in efficiency, when the cobot is used in its collaborative mode.

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