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Lean Optimization for Electric Meter Production

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This project was carried out for Aidon Oy, a Finnish smart meter service supplier company. The purpose of this study was to improve and optimize the production of smart meters produced at Aidon Oy's Customization Centers. A smart meter is a device that measures and controls different values and provides the values remotely to the distributor of electricity.

This study focuses on the improvement of Vantaa ACC's layout and 5S structure using Lean theory and methods. The goal was to gain a view of the current situation, notice the wastes, design improvements and implement those improvements or give direct instructions for future improvements.

The source material used was industry literature, online material and interviewing of the project managers and workers.

The improvements were implemented, resulting in faster production times, increased available inventory space and in a limited amount of products in WIP and, thus, lessened costs.

Keywords	lean, electric meter production

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Tämä sähkötekniikan insinöörityö tehtiin älykkäitä sähkömittarijärjestelmiä tarjoavalle Aidon Oy:lle. Työssä tutkitaan nykyisten Vantaan ja Norjan tuotantokeskusten optimointimahdollisuuksia Lean–teorian ja menetelmien kautta. Menetelminä käytettiin 5S- sekä layout-muutoksia.

Työn tavoitteena oli saada kuva nykytilasta, havaita hukan lähteet, suunnitella parannuksia sekä toteuttaa tai ohjeistaa ne toteutettavaksi.

Työn lähdeaineistona käytettiin alan kirjallisuutta, uusimpia verkkomateriaaleja sekä haastatteluja.

Toteutetut parannukset mahdollistivat nopeamman tuotantoajan, suuremman varastopinta-alan sekä näin rajoittivat keskeneräisten tuotteiden määrää ja niihin sidotun rahan määrää.

Avainsanat	lean, sähkömittarituotanto

Contents

Concepts

5S	A method for organizing the workplace. Comes from Sort, Set in Order, Shine, Standardize and Sustain
ABC-Analysis	A method for the classification of inventory
C/O	Changeover time, time to switch from producing one product type to another
C/T	Cycle time, the time for the part of the process, until the next part is processed
DSO	Distribution Service Operator
ERP	Enterprise Resource Planning
ESD	Electrostatic discharge
ESD	Energy Service Devices
FIFO	First In First Out
Jidoka	Automation with a human touch, automation of problem identification
JIT	Just-In-Time, products are produced just on time based on a pull system
Just-in-Time	Producing things when they are needed using pull production, just on time
Kaizen	Literally translated "Improvement", a philosophy of continuous improvement
Kanban	A visual guidance system for production
L/T	Lead time, the time for the whole process
Lean	A concept of maximizing value while minimizing waste, influenced by TPS
One-piece-flow	Processing of one flow unit at a time, meaning a batch size of one
P/T	Process time, the time spent with the worker
Pull production	Limiting the production only to downstream orders. This means that the amount of WIP is automatically limited. Examining pull production using Little's law tells us that the lead time becomes faster even when production quantity is still the same.
TPS	Toyota Production System
VSM	Value Stream Mapping

1 Introduction

1.1 Aidon Oy

This thesis was made for Aidon Oy. Aidon Oy is the leading supplier of smart energy metering systems in the Nordics with more than 1,5 million Energy Service Devices (ESD) delivered and in operation. The company was founded in 2004 in Jyväskylä, Finland, starting with the development and delivery of its system solutions first in Helsinki, Finland and Gothenburg, Sweden. It is currently the market leader in Finland and in Norway, with offices in Finland, Sweden, and Norway. It has 56 local employees in addition to 60 agency workers and a budgeted turn-over of 42M€ for 2016. The smart energy metering system devices are customized in Aidon Customization Centres in Vantaa, Finland and in Oslo, Norway. (1.)

1.2 Background Information and Goals of the Project

Aidon has 1.5 million orders due 2018 and has just recently opened a customization center in Norway. There is a clear demand for improving and systemizing the Lean production system that was first introduced with 5S changes in 2008, but which has then slowly outdated. Currently the newly opened Norway customization center is out producing Vantaa, but the expansion of market share area and upcoming orders create a need for some layout re-designing, 5S improvements and new standards.

The goal of the project was the general study and improvement of the Lean system in use in Vantaa and possibly Norway production sites. The main aims were the updating of factory layouts, improvement of changeover times and listing possible future improvements. The project was limited to only study the processes between material arriving and leaving the ACC.

The theory part of this thesis will discuss the general history and philosophy behind Lean and some of the popular methods used to implement it. The practical part consists of the improving of the layouts using these methods.

Calculations, layouts, production times and sums of money will not be revealed in this thesis in order to preserve trade secrets.

2 Aidon Oy

2.1 Business Plan and Customers

Aidon's customers are distribution system operators (DSO), service providers and advanced metering management (AMM) prime contractors. As a company, Aidon provides complete management of smart electricity distribution network systems with the use of smart energy metering systems. These systems measure energy consumption and generate measuring data which is then transmitted wirelessly to DSOs reading systems. The architecture used includes all the elements needed by DSOs to collect data from the power grids as well as to link that data to their business systems. (2.)

The solution provided by Aidon is future focused and flexible, with multiple communication technologies. The ESDs improve upon old meter technology, with smart sensor technology and remote connection possibility. The sensor information can include faults and events such as missing phases, over and under voltage and 0-wire failures, which otherwise would be difficult to locate and detect. It also provides DSOs a way to handle cut-offs and reconnections of temporary subscriptions.

2.2 Products

The product catalogue includes 3- and 1-phase smart meters and their communication modules and supplicants, such as independent communication devices to extend the radio network coverage and allow easier maintenance indoors or outdoors.

The key features of ESDs include:

- Remotely controllability, which means a circuit breaker can be used to cut-off or reconnect temporary subscriptions or minimize harm with interference.
- Remote data generation at predetermined intervals. It allows for the monitoring and measuring of the supply quality throughout the entire distribution network, leading to validating losses and locating their sources.
- Monitoring of loads, which allows for planning of maintenance trough predicted lifespan.
- A wide variety of system communication modules: master and slave modules using RF mesh network, RS-485 loop network or standalone installations through direct P2P connection with 2G/3G/4G or existing network.

- Integration to DSO systems, which allows remote status, configuration and software updates. Software upgrades enable new applications and functionalities during the devices lifetime
- Modularity, which allows the communication technology to be updated, lengthening the meters' lifespan. (3.)

When customers decide which communication technology to use, they must take into account the following:

- Availability of suitable communications infrastructure
- Density and amount of metering points
- Geographical topology
- Technological and operational requirements
- Initial investment and operational lifecycle costs

The most popular solution is the autonomous RF mesh network, in which an automatically re-routing micro network handles the environmental conditions. The second most used solution is a point-to-point solution with a direct connection to head-end system via cellular or fiber networks. The third alternative is wired RS-485, which is used in locations where all the metering devices are located in the same space. (4.)

Aidon provides tailored solutions and services such as deployment of new functionalities as well as project, service and support assistance on every stage of the systems' lifetimes. This helps customers to develop and manage their Advanced Metering Management (AMM) systems for the best performance e.g. through versatile raw data collection from the network, high performance of the radio network and easy integration possibilities.

2.3 Vantaa and Norway Customization Centers

The devices are customized in Aidon Customization Centers in Vantaa, Finland and in Oslo, Norway. These production sites differ in size and in their most common types of orders, with a growing emphasis on the Norway production with RF modules. The Vantaa production site is the oldest. It has five production cells and a dedicated repair and module assembly area, with approximately six production workers during the winter and doubling in the summer. The production site in Norway was opened in 2016. It has seven production cells, a bigger warehouse and almost double the workers in two shifts.

3 Lean Theory

Lean is a philosophy and a way of thinking, with different methods at different levels of abstraction (10, 83). Lean philosophy is based on the work made by Toyota starting from the founding of the company in 1937 and accelerating in the 1950s after the war. Japan’s location compelled Toyota to act in a scarce economy with a lack of materials. This meant that Toyota had to produce cheaper and with fewer materials. Toyota learned from the mistakes of Western car manufacturers and based its philosophy on *jidoka* and *just-in-time*. By the time war had ended, it began implementing U.S. wartime industry improvement programs that the U.S. companies quickly forgot about. From these methods and by continuous improvement forced by the environment, Toyota created a system commonly referred as Toyota Production System (TPS). In 1988 the concept of Lean was created in and for the Western world, basing much of its methods and philosophies on TPS. (6, 68-69; 11.)

3.1 Definition of Resource and Flow Efficiency

Resource efficiency focuses on the efficient use of value-adding resources within an organization, so that those resources are utilized as much as possible. This is the traditional form of efficiency, around which Western industrial development has been built. Largely accounting for this is the economic perspective of opportunity cost, which causes loss by not utilizing resources to the fullest.

Flow efficiency focuses on the unit that is processed in the organization. It is relatively new in Western modern industrial manufacturing, yet there are mentions of it even in sixteenth-century shipbuilding. In industrial use, flow efficiency is based on a unit. A flow unit is a unit of analysis, such as a processed good, customer or money. The flow unit in case of a good usually has different stages in which the unit is processed until the unit is finalized as a final product.

As a measurement, resource efficiency indicates how much a resource is utilized in relation to a specific time period. It can be measured at a higher or lower abstraction

level, from machines to organizations. Flow efficiency is measured by how much a flow unit is processed from the time a need is identified to the time the need is satisfied. (6, 9-14.)
Focus on resource efficiency will lead to secondary needs. As defined by Little's law:

$$Throughput\ time\ =\ flow\ units\ in\ process\ x\ cycle\ time \qquad (1)$$

Long throughput times may cause some material to become outdated and need reworking. There may be some tasks that should be processed now, yet the employees are too busy. These delays may then delay others and cause a chain reaction of even more problems. These tasks will need management and the increased inventory need maintenance. This will in turn create human stress.

Too many flow units at the same time force an organization to invest in additional resources and develop structures and routines. In manufacturing a low flow efficiency will increase inventory, which will require storage space leading to other costs such as administration. Large volumes of inventory and work-in-progress make it more difficult to have a good overview. This leads to time and effort spent looking for materials. Inventory also causes extra movement and transportation. These are all secondary needs that only exist because the organization has to handle a large number of flow units. (6, 54.)

An efficiency matrix of a process or a company can be created to illustrate the predictability of demand, flexibility and reliability of supply.

In Figure 1 below, the upper left area represents a highly resource efficient process, while the upper right corner signifies a highly flow efficient process. The upper right corner will be limited by an efficiency frontier, which is caused by variation. Variation can never be eliminated and as such the frontier cannot be outreached. Yet this upper right corner will always be aimed at and the effect of the efficiency frontier will be strived to be pushed as far as possible by eliminating as much variation as possible.

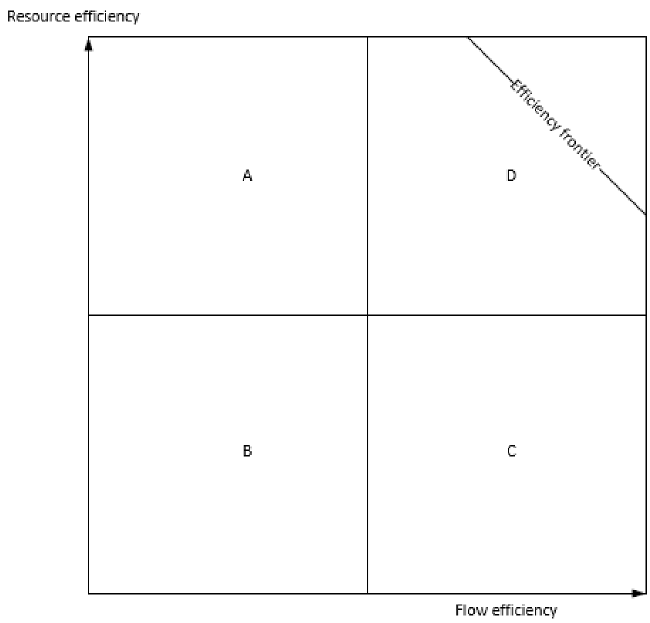

Figure 1, efficiency matrix

The starting point for companies beginning to implement a Lean approach lies usually between points A and B, which then progresses closer to C, and with continuous improvement continues to rise closer to the upper right corner of D. (6, 121.)

3.2 TPS and Lean Principles

TPS philosophy is based on doing things right and to ensure implementation, it has a set of 14 principles:

1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.
2. Create a continuous process flow to bring problems to the surface.
3. Use ‘pull’ systems to avoid overproduction.
4. Level out the workload.
5. Stop the process if necessary to fix problems in order to get the quality right the first time.
6. Standardize tasks and processes for continuous improvement and for employee empowerment.
7. Use visual control so that no problems are hidden.
8. Use only reliable, thoroughly tested technology that serves your people and processes.
9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.
10. Develop exceptional people and teams that follow the company’s philosophy.
11. Respect your partners and suppliers by challenging them and helping them improve.
12. Go and see with your own eyes in order to understand the situation thoroughly
13. Make decisions slowly by consensus, and implement decisions rapidly
14. Become a learning organization through relentless reflection and continuous improvement. (6, 81.)

From these principles, various writers and researchers have come up with a set of principles, the core of which being:

- teamwork
- communication
- efficiency and elimination of waste
- continuous improvement

Indeed, the implementation of these principles cannot be copied from a company to another company, because the specific context needs to be taken into account. This is the main reason why many Lean projects fail or don't reach the goals they were thought to reach. To help implement these, five more principles (or steps) were created:

1. Value specification from the customer's standpoint
2. Eliminate all non-value-adding steps by value streaming
3. Make the remaining steps flow smoothly
4. Create a flow by pulling from the next process upstream
5. Repeat until perfection is reached and no waste is created. (6, 77-78.)

In addition to the official principles, researchers have come up with four invisible rules at Toyota:

- All work should be highly specified in content, sequence, timing and outcome
- Customer-supplier connection must be a direct yes-no communication
- Pathway for products must be simple and direct
- Improvement must be made under guidance using scientific methods and at the lowest possible organizational level (6, 79.)

3.3 The Three Evils

According to Toyota, three types of evils exist in manufacturing.

Overburden – (無理, Muri)

Overburden can be easily described as abusing workers or machines more than what they can keep up to, which will lead to either breaking equipment or burnt-out employees.

Unevenness – (斑 or ムラ, Mura)

Unevenness is closely related, often being the cause of overburden. A way to view uneven and even production is trough comparing batch and mixed production. Traditionally all manufacturing has been organized in large batches to maintain high resource efficiency. Batch production is illustrated in Figure 2 below.

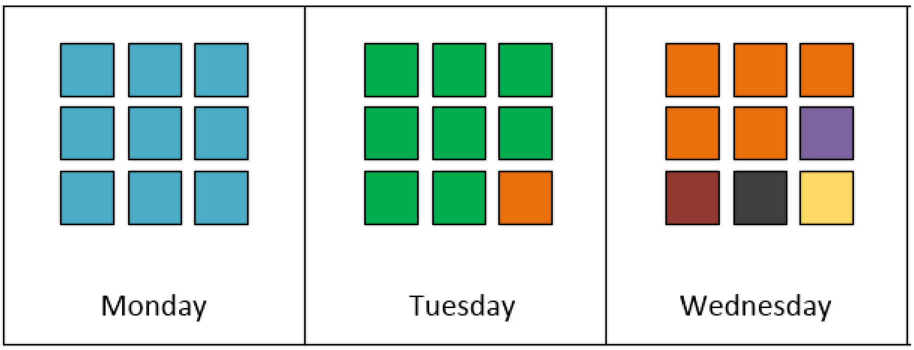

Figure 2, an example of batch production. Different colours indicate different product types.

In a leveled production the batches are smaller and production more even, as shown in Figure 3.

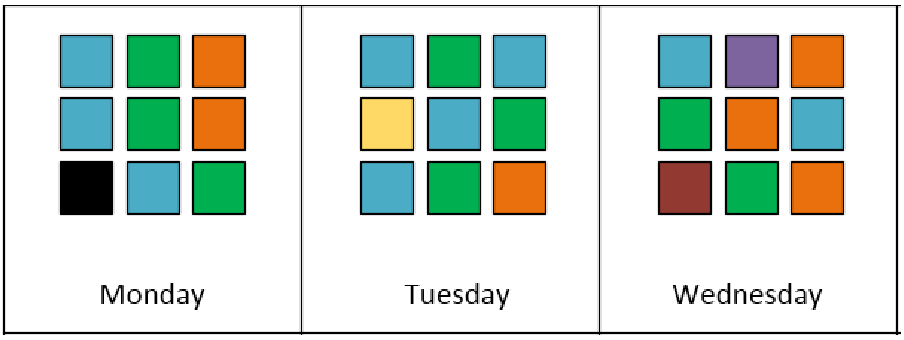

Figure 3, general principle of mixed production.

This allows for smaller lead time and added resiliency in case of malfunction or fluctuation of demand. Yet to function properly it requires flow improvements such as smaller changeover times and balanced cycle times to ultimately allow a one-piece-flow. (7.)

Waste – (無駄, Muda)

Waste is seen as the most important of these evils. Toyota has identified waste in seven forms:

- Waste of overproduction. Each step should always produce only what the customer needs
- Waste of time on hand (waiting). Production should be organized to avoid all unnecessary waiting, both for machines and workers
- Waste in transportation. Avoid transporting material and products, by changing the layout of the factory.
- Waste of processing itself. Avoid doing more work on a part or a product than the customer requires; this includes using tools that are more precise, complex, or expensive than necessary.
- Waste of inventory. Inventory represents capital that is tied up in the process and hides problems; it should be avoided by means such as reducing machines' set-up times (the time it takes to change a machine from doing one thing to doing another).
- Waste of movement. Organize the workplace so that workers do not need to move in order to do things such as gathering material or fetching tools.
- Waste of making defective products. Every step in the production process is responsible for producing only fault-free parts. (6, 73.)

Most important of these is the waste of inventory, as the cost of inventory usually lies between 30% and 65% of the inventory value per year. These costs come from:

- Cost of capital
- Taxes and insurance
- Storage cost
- Handling cost
- Administration
- Scrapping and obsolescence
- Deterioration and theft
- Cost of delayed response time (8.)

The high costs often make inventory the first issue that companies wish to improve. Theoretically, this can be solved with one-piece-flow and by producing just on time (JIT). The graph in Figure 4 below illustrates the effect of batch sizes on inventory.

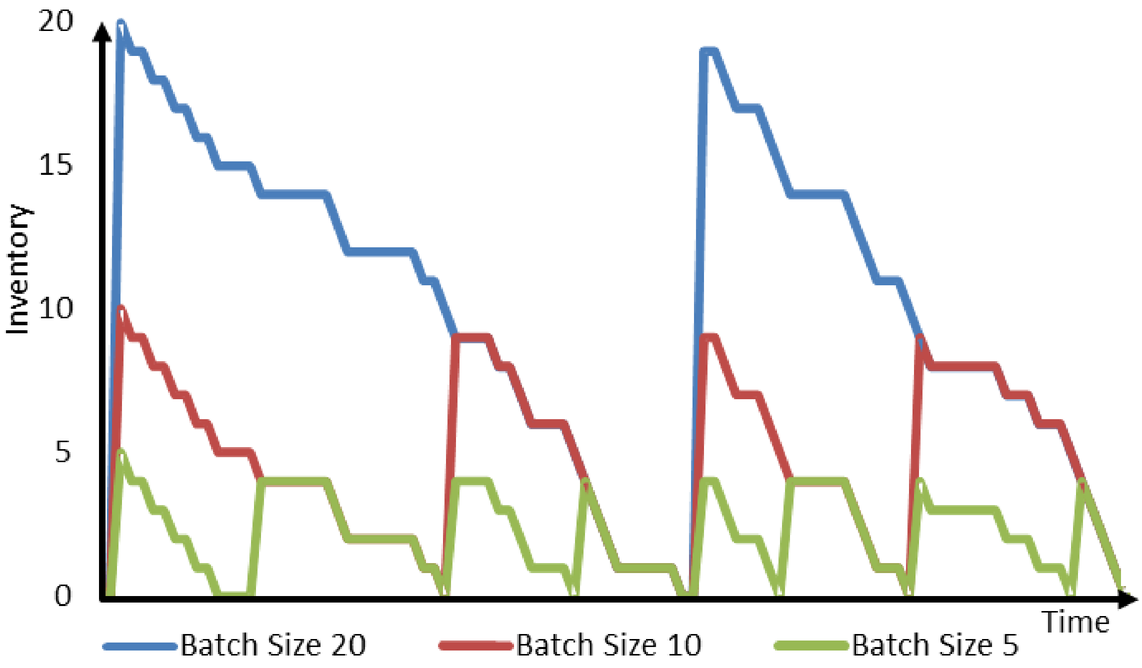

Figure 4, the effect of batch sizes on inventory (9).

In an ideal situation the batch and inventory size would be one, which would lead to high inventory rotation. In practice, larger inventories and batch sizes will be needed to account for the fluctuations in production, orders and transportation, and to find a reasonable balance in cost-effect, as transportation costs would otherwise increase dramatically.

When implementing a one-piece-flow, production halts are to be expected. These halts will put pressure on the management to improve quality and solve the problems. With time, the halts ought to be less frequent. To reach the ultimate goal, slow yet continuous improvement is recommended by making small gradual decreases in inventory. (9.)

3.4 Value Stream Mapping (VSM)

Various tools are used to implement the Lean principles. An often used starting tool is called value stream mapping. A value stream map is created by personally walking along the process flow and at the same time timing the various processes. This is all hand drawn in a map. An example of a value stream map can be seen in Appendix 1.

The map consists of the flow processes with specific information marked on each process, including the sizes of inventory, changeover- and cycle times and the amount of operators at the process. The idea is to illustrate the VA- and NVA-processing times and the direction of the flow of material. It is usually product type or family-specific. The map will give a general outlook on the flow process, which will then help to see places for improvement. Usual outcomes include setup time reduction, complexity reduction, inventory reduction and capacity improvement by balancing and improving availability of machines. (5.)

3.5 Spaghetti Diagram

A spaghetti diagram is about drawing the flow of workers and material on a map. This will help to improve the layout as it highlights waste movements. An example spaghetti diagram can be seen in Section 6.7.

3.6 5S

5S is a tool for organizing and cleaning the work place. It is a daily process and model that is part of the job. All unnecessary tools and items that block the flow of items are removed and the rest is sorted. The goal is to shorten lead times and improve flow. 5S steps derive from Japanese and are the following:

Sort – (整理，Seiri)
Sorting of the material and the tools: leaving the necessary and removing the rest.

Set In Order – (整頓， Seiton)

Tools and material are organized in practical, easily reached and visibly marked locations, with efficiency, safety and ergonomics in mind.

Shine – (清掃， Seiso)

The tools are cleaned and serviced or replaced. All dirt and dust is removed.

Standardize – (清潔， Seiketsu)

A standardized level of cleanliness and an order of tools is created. Visual guidance for the easy upkeep of the standard is created.

Sustain – (躾， Shitsuke)

The maintenance of the first three S's by forming a habit. This is the most important S and will require commitment, otherwise failing the 5S. (10.)

3.7 ABC-Analysis

ABC analysis is a method to classify items into three categories, according to their relative importance based on the total annual expenditure for each item. The high value or most important items are then given more attention. The three categories are defined as follows:

- A-category items are especially important with highest value
- B-category items are of average importance with medium usage value
- C-category items are minimally important with lowest usage value

It is often observed that about 20% of the items account for 80% of the total usage value. These A-class items should have tight inventory control, meaning secured storage areas, frequent orders and good forecasts. C-class items should be reordered less frequently with smaller safety stocks. They are often managed with material Kanbans. B-class items are an intermediate between A and C. These items should be monitored for the potential evolution towards class A or C. (11.)

3.8 Visual Management

Visual management is a general practice of making communication and problems more visible to improve reaction. In practice it can mean problem tracking management boards, production indicators, heijunka boards with daily schedules, 5S markings, light indicators, FIFO racks, 2-box systems or Kanban cards. (12; 7.)

3.9 Kanban cards

Kanban cards are used to automate ordering, inventory and producing. There are two main types of Kanban cards, one for production and one for material. At minimum, Kanban cards have an Item ID and the amount of items marked in their respective card. A Kanban card is always either attached to a flow unit or material or waiting for processing at an upstream location. The location is usually a designated place where the card will then be picked and another unit be produced or material fetched according to the card. Material cards may also include instructions as to the ordering of the items. Production type Kanbans usually show the number of cards in circulation and the location for the production and the usage of the item. The reason Kanbans are used is to give a visual indicator to schedule production, to limit the amount of items in circulation and to implement a pull material flow. (13; 14; 15.)

4 Depth of the Work

As mentioned before, the aim of this work was the improvement of the process between the receiving of material to the sending of finalized products. The improving of the organization of material handling and purchasing or the sizes of orders will be left for a future projects. Vantaa ACC was chosen as the first objective, with Norway starting later, so the thesis will begin with Vantaa.

5 Research Methods

5.1 Research method for 5S

The research and classification was implemented by interviewing the workers and utilizing my own experience in the company. The ACC in Vantaa has five production cells and three repair cells. All the repair workers and a few of the cell operators were interviewed using informal questions as needed. Research started with clearing and making an inventory of the current tools followed by asking for the need frequency and reasoning for each tool, unless the answer was already known. The aim was to categorize the tools which were used daily, weekly or monthly.

5.2 Research method for VSM

The value stream mapping was implemented by following and timing the work phases and by further interviewing to get the general picture. Combined with existing knowledge, this revealed where and how the tools and materials needed were gathered. Improvement recommendations or wishes were also listened to and implemented when possible.

5.3 Research method for management

The management and the coordinator of this project were interviewed whenever needed and continuous meetings were held where the progress of the project was discussed, clearing any problems encountered. The questions for management were mainly about the new layout solutions, taking into account the management's wishes and the uniformity of the cells.

Based on these interviews the new layouts and changes were planned as discussed in this thesis.

6 Beginning State at Vantaa ACC and Problem Cases

The state of ACC Vantaa will be described in this section, beginning with the efficiency matrix by listing the flow elements and resource efficient elements.

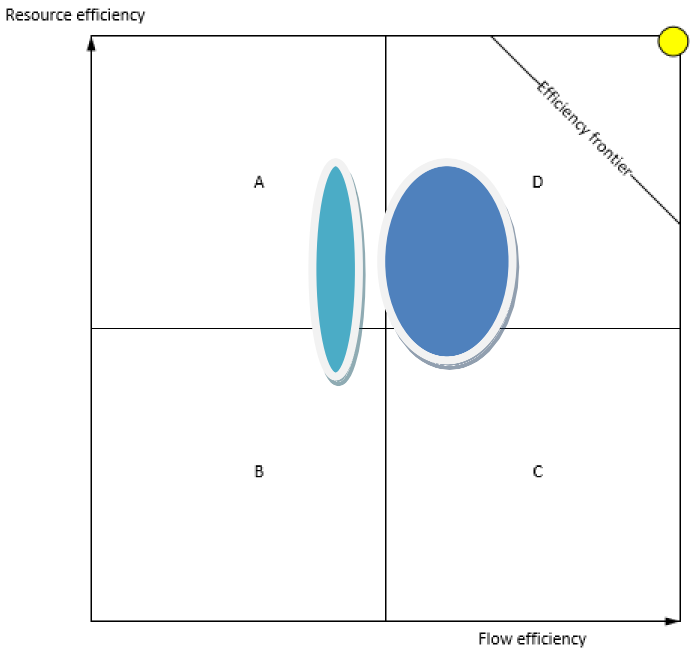

Figure 5, estimated resource efficiency matrix of Aidon as a company and of ACC production line. Blue dots represent the current situation, yellow dot represents the ideal situation.

The reasoning for the placement of the blue areas in Figure 5 is as follows:
Workers have high resource efficiency, with a rather high value-adding share. The machines are also in use at least 70% of the workers time. This would give high resource efficiency. This all depends on the available inventory, which causes the high variation and thus larger dots. Flow efficiency on the other hand, is quite low. This is mainly due to the importation of material from other countries such as China, which requires larger inventories to account for fluctuations. The orders themselves generally have about one week of processing time until the deadline. The work cells have a buffer inventory of 10 to 280 pieces. The module assembly has no exact WIP limitation. The finalized products are packed in the order of nearest deadline or in case the packing area is full. Thus Aidon would be positioned organizationally at the light blue area, and with the effect of China excluded, production work at the darker blue area. This project will aim to reach the right side of the dark blue area more often.

6.1 Visual Guidance

The beginning state of visual guidance is fairly low. The cells have high walls with no visual contact to the module assembly or to the module shelves, as demonstrated in Figure 6. The walls also limit visual and vocal contact with other testing cells and thus cause waste movement in problem situations.

Figure 6, beginning state of a work cell

A 5S board does exist, but it is located far away and not really being used. There are markings on the floor for dividing the areas.

6.2 Worker Roles and Stages

The work is divided into three different roles. To begin with, the material received and sent is handled at the packing area, which is usually taken care of by one or two people. Secondly, there are the production and repair workers who work either at the testing cells as operators or at the module assembly flashing and assembling the modules used. These are the most laborious parts, and there are usually from one to twelve workers in these roles. Finally, there are supervisors managing the workload.

6.3 Work Guidance

The flow of work is guided by a system of work cards. The supervisors add work cards to a holder, from which after finishing a previous order the operators or module assemblers pick a new order and begin to produce. A finished work card is marked as finished with the initials of the worker and copied on the finished pallet. The original copy is taken to a finished orders box. The production process is only started when an actual order is made, yet no WIP limit exists. The work is prioritized by the suggested delivery date, but the operators have a freedom of choice unless instructed otherwise.

6.4 Management

The production team leaders basically prepare the new and handle the finished work orders and take care of the problems discovered during the work. The team leader keeps track of production schedule and may assign bonus hours to increase production and motivation for the day. The work cards are verified to include the correct meter, module, label, and nameplate version and also the correct accessories when needed. Management is not within the scope of this work, so it will not be discussed in further depth.

6.5 Material Handling

The material handling is divided between many workers. The worker at the packing area uses a digital Lean system to see current, future and past orders. With its help, the leaving products are prepared and marked in the system and incoming material unloaded to their places and marked in the system. A warehouse inventory is done at scheduled intervals and takes up to three days. Defect material from production is taken to an assigned place and returned to the manufacturer when the areas for them seem to be full. Packaging material such as plastic wrapping is recycled and reused when needed, with assigned places for bubble wrap and cardboard boxes.

6.6 Layout

The current layout in Vantaa has four normal U-shaped work cells and a fifth power cell with automated printing. All the meters are taken from the loading area into the meter area, from which the meters are then picked to the work cells.

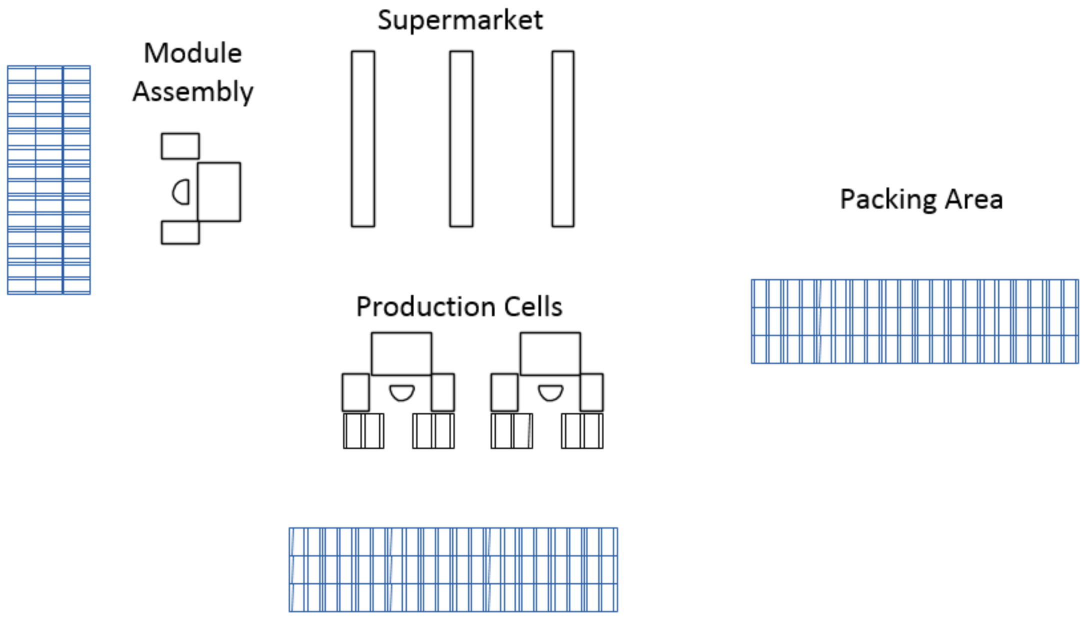

Figure 7, a general purpose 2-D Layout of a production factory

Figure 7 illustrates a general factory layout with different phases in different locations. At ACC Vantaa, the module assembly is located next to the module warehouse, quite similarly as in the illustration. From there, the assembled modules are taken into the storage shelf or directly to the cells.

6.7 Work Phases and their Wastes

A spaghetti diagram was created on top of the layout to illustrate waste movements. A general idea can be gathered from Figure 8 below.

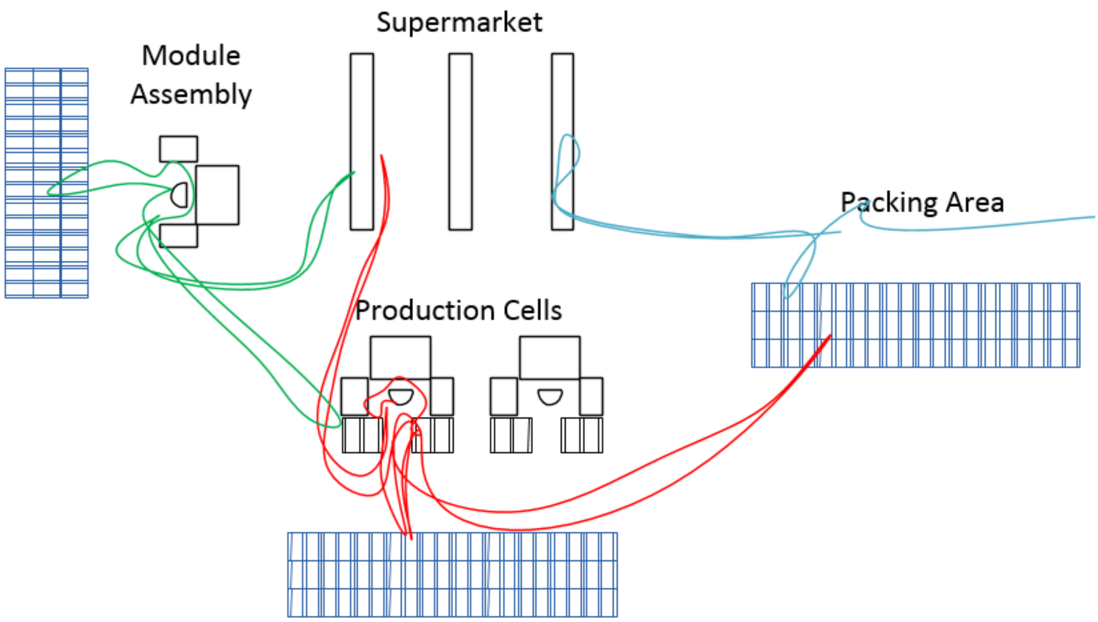

Figure 8, a generalized spaghetti diagram of the movement of production workers

The spaghetti diagram is marked with colored lines denoting different roles. Red lines show the movement of a testing cell operator, green lines show a module assembly worker, and finally blue line shows the packing worker.

6.7.1 Cell Operator Waste

By examining the spaghetti diagram the main operator waste was determined to form primarily from the walking between the cell and the packing area and between the cell and the module shelf. Depending on the work orders, the operator might visit the packing area from one to eight times a day. The movement to the module shelves is more frequent, varying from once a day to 20 times a day.

The main movement happens inside the work cell and between the cell and the module shelf. The movement inside the work cell is quite optimal, with some room for improvement by eliminating tool searching waste with 5S. Because of the lack of visual or vocal contact to the module assembly, missing modules sometimes cause waste movement.

More waste was located in the changeover times. The phases when finishing work orders include: copying the work card, fetching the fork lift, adding the copy of the work card to the pallet, taking the pallet to the packing area, taking the fork lift to the cell, returning the work card to finished orders, picking a new work card, searching for the meters, taking the meters and returning the fork lift, opening the pallet, removing trash and possibly changing the fixture. Some of these phases could either be eliminated or improved by shortening distances. Other infrequent waste include locating SIM-cards and correct fixtures, changing defect material, needing to repair the testing fix or needing to correct the printer.

6.7.2 Module Assembly Waste

Module assemblers will pick the order, gather the material, print the labels, flash the modules, assemble the modules and take them to the module shelf. They will also take care of the box recycling. The biggest waste found was the walking distance to the work papers, to the printer and to the module shelf. Other waste includes the walking to the cardboard recycling and material refilling. These distances may be improved.

6.7.3 Packing Area Waste

Packing area work consists of mostly time consuming paper work at the computer, which is not included in the depth of this thesis. Besides the paper work, packing will add additional material to orders and finally pack and wrap the pallets. Packing will also unload incoming materials and reorder the warehouse. The work flow is mainly spent at the packing area, with miscellaneous accessories located and picked from the warehouse shelves. Incoming material is taken into their places at the module area or new meters at currently free locations. Sometimes this requires looking for free space. This searching and the walking between the warehouse and the packing area can be described as waste.

7 Improvement Plan

7.1 Correcting the Wastes

To take a first step towards change is to change the layout. Waste at the module assembly could be reduced by making everything more compact, which seemed possible by moving the assembly next to the module shelf, as discussed in the coming section. Operator cell waste could be readily improved by implementing 5S and by changing some of the work phases or movements. The easiest first solution would be a closer location for trash, wooden pallet topping and a fork lift. The work cells could be made symmetrical and paths to the module assembly made as short as possible. Packing workers' non-value-adding mainly accumulates on the path to the accessories warehouse, which could be improved by relocating the accessories.

7.2 Warehouse Changes

The accessories warehouse items should be inventoried and the frequency and location of use assessed. These factors define whether the item should be trashed or moved to another location. The packing accessories should all be moved to the packing area shelf, with unused material in the packing area moved to the outside warehouse. New shelving could be created for testing accessories at the old module assembly location. According to the Lean principles the module shelf should only hold modules, tape rolls, cleaning equipment and a standardized amount of plastic bubble wrap boxes.

7.3 New Layout

New layout propositions were made, and after a few feedback rounds and revisions, the plan was improved to allow for a more direct contact with repair personnel, more warehouse space and an even more compact module assembly. The generalized final layout plan can be seen in Figure 9.

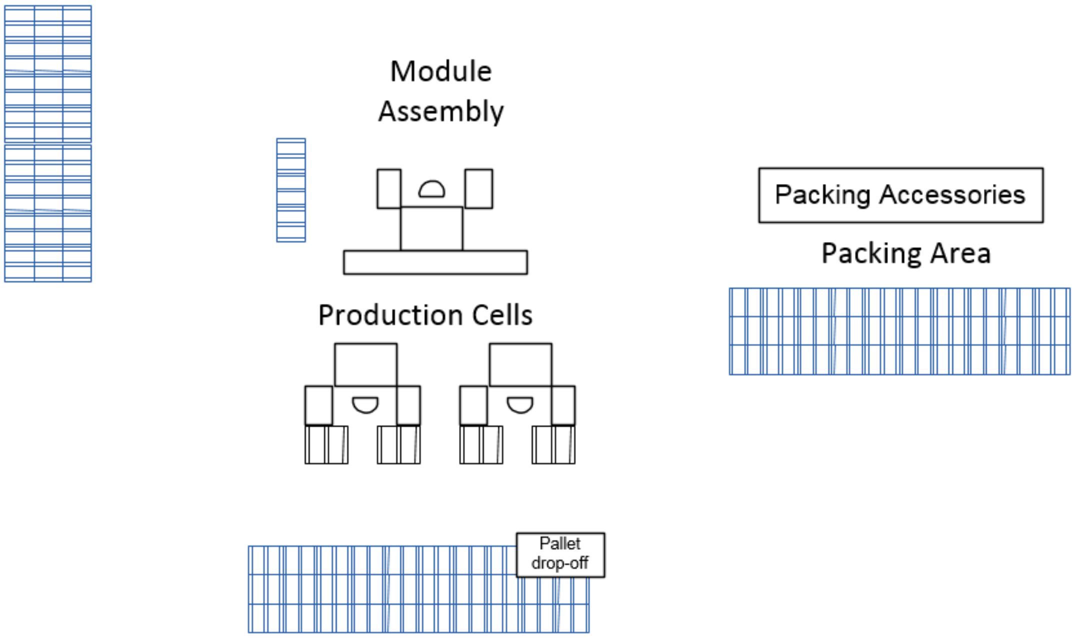

Figure 9, generalized final layout plan

The rationale for the changes will be explained in the following sections.

7.4 Visual Guidance

The most impactful visual improvement could be gained by lowering the cabinet wall frames so that the cells would have a direct view to the module assembly. The new location of the module assembly would allow for more direct feedback between the testing and module assembly, which helps to adjust division of labor. A negative side effect will be discernible in the general noise level, but it will likely remain under tolerable levels.

To improve the visual management and the formation of a big picture, a visual board should be introduced. The board could include a listing of 5S areas and responsibilities alongside a map with emoticons to give 5S feedback on the areas. The board could allow an easy way to track people being present/away/at Norway, current and near future workload, problems/feedback tracking and other notable information. The information on the board is to be updated and reviewed every day or week as described in the daily management section below.

7.5 Refresh and Improvement of 5S

The current 5S system was implemented around 2008. There is a 5S board with rules and some instructions, yet the system has not been maintained. The work cells should be assessed as to their cleanliness and the availability of necessary tools. The maintenance could be improved by sorting the tools, adding visual guides, adding cleaning rags, and by assigning a responsible worker for each area. Specific 5S-minutes can be held to maintain a frequent evaluation by assigning 5 minutes at the end of each day for the cleaning and evaluation of the work cells.

7.6 Module Assembly

To improve the waste at the module assembly area, the area will face the most alterations, such as a new location, less moving and less table and shelf space. Some equipment would need to be removed or modified. A new work in progress (WIP) limitation system should be introduced along with the visual board with workload information, which would direct the amount of modules and other material taken each day to the module assembly area from the warehouse. The module assembly would then only produce those kinds of modules not available at the full storage capacity or entirely absent from the shelf.

The buffer inventory next to the module assembly should include the cover material and the modules needed for that day or that week. The locations for the boxes when doing single or dual work should be fixed, and the fastest way of returning the box to the shelf should be standardized. The existing computer with module label printer should be solely utilized and modified to work with all types of orders, eliminating the movement to the previous printer.

The biggest savings can be made by reducing movement, which could be further improved by making the shelving FIFO-like, allowing direct input from the assembly side. Because of the wide array of module products currently, replacing the shelf itself with FIFO lanes seems difficult.

7.7 Repair

The repair location would be moved a bit further away from the repair warehouse, but the changeover times being only a small part of the lead time, it was acceptable. The closer proximity to the supervisors would hopefully increase cooperation and improve the resolving time of the repair work. The shelf area for repair would decrease which would lead to more frequent cleanup and less unused modules.

7.8 Worker Roles

The division of labor would become more flexible and self-adjusting through the direct visual contact to the module shelves. Being aware of each module production cycle time increase and available module count diminish would allow workers to independently change their roles at a quick notice.

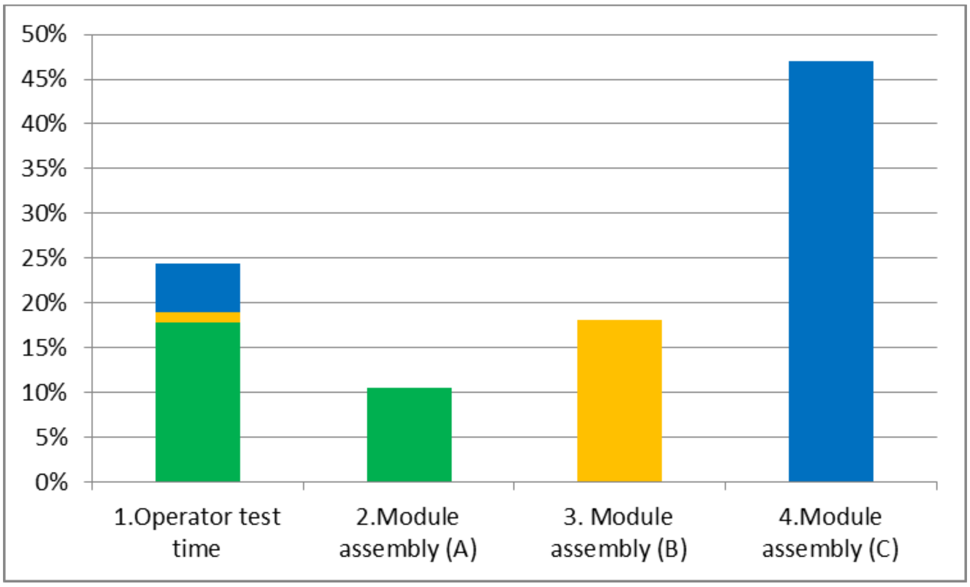

Figure 10, old load balance diagram

Figure 10 displays the old load balance between the production and the module assembly. This balance is not easily addressed only by changing the distance, but some improvement can be made with the C-class modules by eliminating the distance, as can be seen in Figure 11.

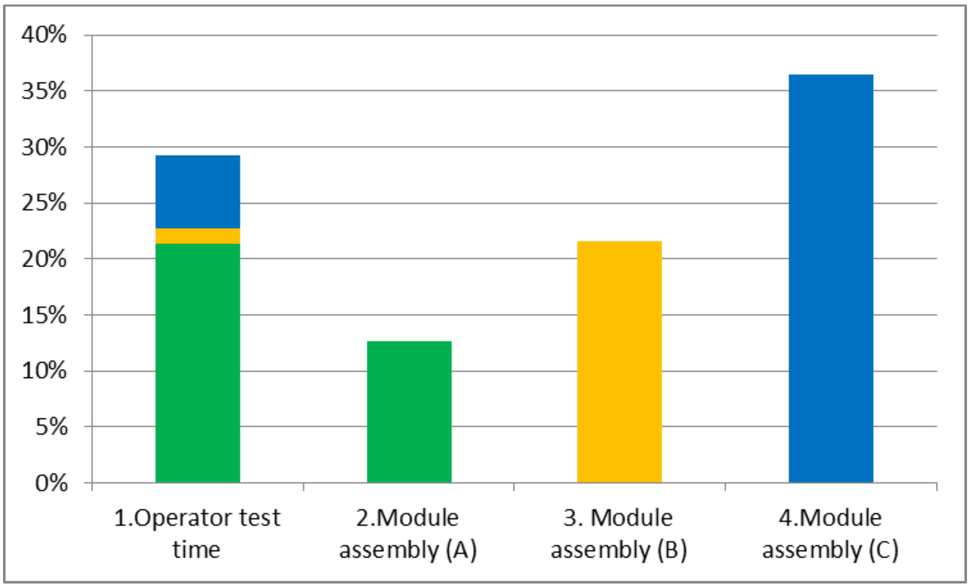

Figure 11, new load balance diagram

The loads will stay pretty even, with close to 1:2, 1:1 or 2:1 ratios each. The changes in cycle time would be minimal for others than C-class production yet still slightly improving. Change times would improve with processes, most being in the packing.

To maintain these ratios, the module production should only give out good products. This means checking the quality of labeling and connectors.

7.9 Cell Operator

The new plan requires compliance to the 5S rules. The tools in each cell would be marked and thereafter kept in their place. This should be maintained by regular 5S minutes. Direct visual contact to the module assembly and other production cells allows single operators to work on two different cells if the testing process is slow and modules keep piling.

7.10 Lean Daily Management

Lean daily management would count the visual board, work cards and WIP limitation among its tools. The team leaders would have the responsibility of reviewing the work load for the week and coordinate the visual instructions accordingly. The visual board maintains the concept of continuous improvement with problems being listed on the board and their impact and progress shown. The 5S areas would be kept clean with a feedback system evaluating the cleanliness of each area by writing a matching emoticon at the end of a day or week.

7.11 Effects

The final layout would increase the space for material. There exists a clear need for the space, as the supply of material is sometimes unreliable and the safety margins need increasing. The previous area of repair and some of the module assembly area would be assigned as additional space for pallets, to ease the locating of free space for incoming material and to make room for new meters. The lower cabinet walls and new repair area location would prompt a more flow-like type of production and allow visual feedback.

The changes in layout would be as follows:

- Relocating the repair area, creating 12 more pallet places for meters and eight more pallet places for the modules.
- Decreasing the repair table area by one table to prevent trash pileup.

- Assigning proper pallet places and a more functional corridor for repair
- Shrinking the module assembly into four tables from previous six tables
- Moving the accessories into the packing area.
- Moving the seldom used accessories into the upper warehouse
- Moving the rest of the accessories into the new C-F side shelving or trash.
- Assigning a specific limited space for ready modules to limit the production and monetary value bound to ready modules.
- Assigning one pallet place as a trash site and as a buffer for wooden pallet toppings that would be moved once full.
- Cleaning and standardizing paths from work cells to the module assembly
- Moving the print license server to cell number two for faster troubleshooting.

The practical effect of these changes can be seen in the new generalized spaghetti diagram below in Figure 12.

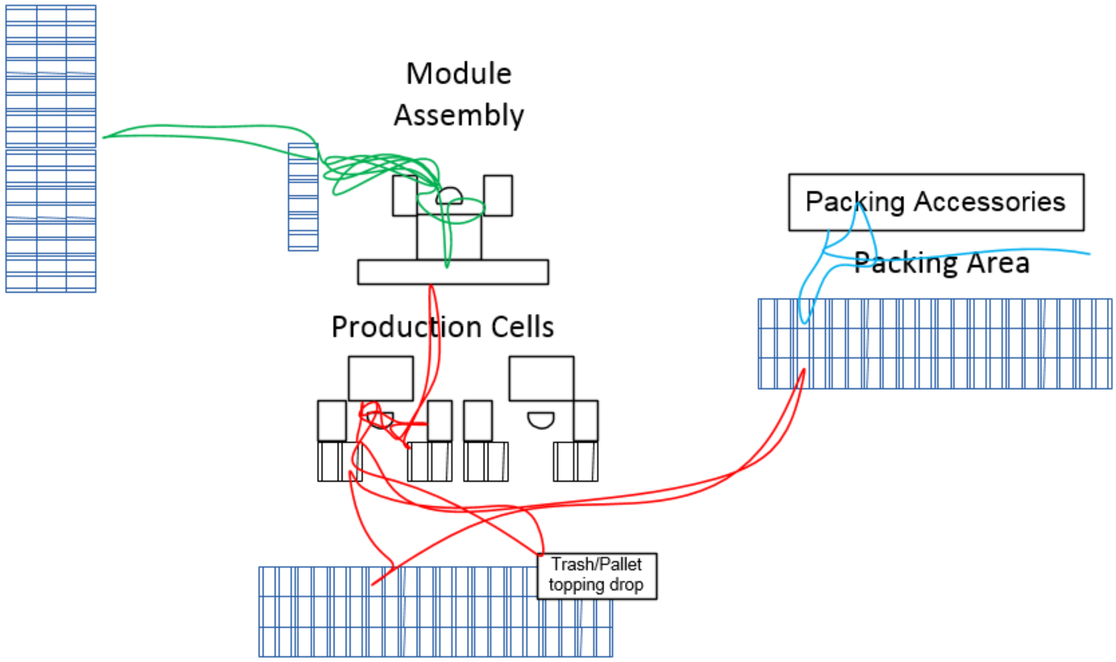

Figure 12, spaghetti diagram of a new generalized layout

When using a high runner product as a reference, the calculated average change in movement would be -70% for module assembly, -58% for meter changeover, -72% change for packing accessories and no change or a small increase for repair.

8 Implementation, Results and Further Improvements

All of the layout moves were successfully implemented during an inventory check-up at the end of the year, with only a little bit of variation due to circumstances.

The work began with the clearing of the accessories warehouse. The accessories were split according to the place and frequency of use, resulting in:

- Packing accessories moved to packing area
- Manuals moved upstairs or trashed
- Rest of the accessories moved to the new C-F shelves
- High capacity work cell moved to Norway, 5th cell normalized and prioritized for repair use

The old accessory shelf structure was recycled by using it as a base for the A-F shelves. In total, three new smaller shelving locations were created.

The cell units were cleared and adjusted to the layout, standardizing the paths and time taken to the module assembly closer to equal, effectively decreased waste time. The cell cabinet wall frames were changed into lower ones according to the plan.

The work cells were assessed as to their cleanliness and the availability of necessary tools. The toolboxes were adjusted to include only the necessary tools as listed in Appendix 2. By adding a foam insert to the toolbox, order upkeep was made easier with a quick visual feedback. Visual guides were introduced to the cells, reminding to keep the cells clean and the tools in their correct places.

The new module assembly location was created according to the planned layout with some slight modifications. Some of the module flashers could be combined into one table, which comparably decreased waste to a minimum when moving between the two stations. New monitor holders were added to increase available space. The shelving was made such that the modules could be inserted directly from the module assembly side, as planned. The defect material area was decreased and assigned separately tape marked shelf space.

The SIM card warehouse was also organized in a numerical order to facilitate locating the material. The ESD protected areas' grounding bar connections were also verified and corrected when needed, which might increase yield. Finally, the floor markings were adjusted to reflect the new setup.

No separate fixture bar was added yet, so the fixtures were assigned shelves in the new C-F shelf, with clear markings for each model, which is still an improvement compared to the past.

Figure 13, view after the layout change

The general change can be seen in Figure 13.

8.1 Familiarization to the New Layout

A quick familiarization session for the workers was held. The new accessory locations were shown and the module assembly was taught to have a small working inventory of material to be filled at intervals. A visual board was added to the corridor, providing the kind of information as shown in Appendix 3. Workers were taught to mark their presence on the visual board, using magnetic name plates. The meaning of the 5S map and the improvements section was explained. The 5S area responsibilities were split between the workers and the evaluation criteria was explained. Evaluation was suggested to begin with inspections on every other day, increasing the span once the processes seemed to flow.

Feedback was gathered from the first two weeks following the layout change.

8.2 Results

The new locations were quite well adapted to by the end of the week. The vicinity of the flashing stations, the module assembling station and the module shelf decreased waste movement to a minimum, enabling module assemblers to work in a more flow-like way. The 5S improvements with assignment of equipment to certain test cells and locations improved the time needed for searching equipment. Due to the increased noise level the response time of team leaders decreased, at the price of slightly less privacy. This effect might need later feedback from the workers.

8.3 Problems

Some problems were noticed after changing the layout and introducing 5S improvements:

- Increased noise level
- SIM warehouse was not kept organized
- 5S not used: tools not in their places, no 5S-minutes
- Bubble wrap amount and location
- Fault cases
- ESD marker tape
- Extension cord location
- Repair pallet locations
- Present status practice
- Module label file

Most of these problems were solved immediately once noticed. The expected increase in noise level was quickly acted on by adding some walls to the new corridor, which helped a little. Further improvements could include raising the walls with window pieces to still preserve visual contact.

A reminder was made to keep the SIM warehouse organized and a note was added. To force the use of 5S, the evaluation minute was hand-managed a few times. To fix the missing tool problem, a few additional tools were added to the module assembly.

The module shelf had a few different test setups and finally the cleaning supplies and tape rolls were assigned next to the defect modules with only the work cards on top of the shelf. The module box insertion was standardized to a specific style and was enforced with visual guidance. Recycling the bubble wrap and cardboard boxes needed some standardizing, so it was decided to limit the bubble wrap box amount to three and to mark their location on the shelf with clear markings. This needed a few repetitions, but was ultimately assimilated by everyone. The card boards were assigned a new cart for easier and tidier use.

Smaller problems were also run into. The repair pallet locations were slightly alternated to allow for different pallet sizes and easier walking paths. It was agreed that these locations could be experimented with and improved later if needed. The visual board presence information was perceived to be difficult, so it was agreed that one’s status could be left as ‘present’ if one would be coming the next day. The module label printer did not have a file for some of the module types, which was then fixed. The ESD marker tape was not holding, so the floor was cleaned and the tape was changed. An extension cord was not easily found, so a new easily found holder was added.

After these changes, the timing had improved as expected. The visual board was also quickly used for informing about a new software version. A slight change time improvement when changing fixtures could be achieved by locating the fixtures next to the cells, as was planned, but this will be left for future. Another solution would be to change the fixtures to work with all meter types, which is the likely way to proceed.

For further ongoing standardization, the frequency of removal and sending back of defect material and the optimal assembly location on the module assembly tables should be experimented with. The module assembly table could also be changed into a less deep one to improve ergonomy.

8.4 WIP Limitation

To further improve the flow of the production and to implement a clearer pull, WIP systems were considered. The change in shelf space itself was already an improvement compared to the previous way, yet this should either be strictly standardized as the maximum limit to prevent modules from piling up on tables etc., or an even clearer system is to be introduced, such as Kanban cards. To research this topic, different systems were inspected. A quick overview of Kanban cards can be found in the theory section.

The problem with using traditional Kanban cards would have been the variance in module types. The module types were ABC-classified to sort out the most common ones. It was found out that some of the modules using customer specific configuration were A and B-class products, which would lead having Kanbans with configuration information. This would either increase the amount of cards and inventory dramatically or, with non-standard customizable cards, add additional management workload for the operator or team leader to mark the configuration and to remove the cards from circulation when not needed, which is unusual for Kanban card use. In case the inventory was increased, software updates might still cause reworking of some modules. A-class variation could be managed, yet the share difference between A- and B-class is not as significant to justify the addition of Kanban cards besides the old system with shelf limitation. In addition, the increased material reserved on the shelf would lead to disassembling some modules in case of late material shipments and competing prioritized orders. In case of the varying A-class module, some buffer for flashed modules could be devised. Otherwise the variation on labels and B-class modules is too high to feasibly make separate Kanban cards productive.

An alternative to Kanban is called Constant Work In Progress (CONWIP). It is a method of limiting the amount of WIP with cards or other methods commanding the availability or need of work force. The definition of CONWIP differs from source to source, but in this case the difference between Kanban and CONWIP is thought to be that while Kanbans define specifically what is produced, CONWIP only defines that something should be produced, leaving the specific determining separately according to preference or priority. A Kanban system will already have the product in buffer, whereas a CONWIP system will only produce once there is an order for it. [15; 17; 18.]

With these systems in mind, multiple alternatives combining and modifying these concepts were thought of.

a) Work cards and static limit: the size of the shelf limits the WIP amount statically and the work cards and usage direct the priority. A distinct clear visual ruling to halt production at maximum limit exists.
b) Work cards and CONWIP cards/boxes/shelf dividers: limit the amount of maximum WIP to a specific amount. Either for whole production or separately for each module type. Allows adjusting according to work force and demand. Boxes require physical inventory. Shelf dividers are easily adjustable. Both require visual contact to the shelf and abiding to the rules.
c) Work cards and WIP limit table: magnetic board with module types and their WIP limits marked for each day. Requires active status marking with markup tools or magnets. The board could be transparent glass with movable magnets on each side to allow 'status' to be moved from both operator and module assembler. Should be located nearby.
d) FIFO trailers. Moved with work cards in batches. This would limit the production WIP permanently. Mixing and batch sizes problematic. Trailers might improve the flow-likeness or decrease movement but might be a bit impractical to move.
e) FIFO shelf with separate lanes for different module types. These could be adjusted according to weekly order amounts. It would be difficult to increase existing space if needed. Required space might be a problem.
f) Load-leveling box with cards that are either not recycled or that are recycled and removed once goal is reached. Requires many cards and much maintenance.

Of these solutions, a CONWIP card system was tested first, with negative feedback coming from the workers. The feedback mostly consisted of the card system not being necessary, as there is a lot of variation in work load and work force, that the current shelf system is already limiting enough, and that the production can be managed directly by limiting the amount of available work cards.

This was all valid feedback, yet it does not allow leveling of production, as the work cards cannot be cut into small enough pieces. Thus, a physical limiting solution for each module type will be the next solution to be tested:

1) The maximum production WIP would be limited by the size of the shelf and this would be strictly enforced by rules and instructing.

2) The production WIP of each module would be limited by physical dividers on the shelves assigned to the three most used module types, with an “Others”-area assigned for the rest.
3) The current work cards are retained, although the work cards are only taken into production when there is space on the specific module area on the shelf.

If there is no space left, the module production is halted and the worker should either go to testing or assess the cause of the slow production, trying to improve it. The proper ratio for modules will need adjusting, but one valid starting point could be to limit the module types according to daily production aim amount for the day divided by the available hours, i.e. one hour of production. The buffer should be kept big enough to allow for the flexible work hours.

9 Norway ACC Improvements

There was not enough time to delve into improving Norway ACC. Yet the cumulated experience suggests that similar improvements could be made through implementing 5S, by improving the layout with the help of a spaghetti diagram and by limiting the share of WIP.

10 Future Improvements

The visual board allows for implementing constant improvement by reviewing Issues/Suggestions frequently. To facilitate this, there should be some type of improvement goals with deadlines. As for the production flow, the current work amount is quite well divided in a 2:1 ratio. To allow for even faster production, the quickest gains could come from increasing the speed of the flashers, from increasing the speed of actual testing and handling of the fix and by making the manual work as little as possible. This also means improvement of error-correction. Proper small batch mixing of the production will probably not be achieved nor will it be efficient until reasonable change-over times have been achieved. Module assembly could be improved by making more universal parts for all modules and making the variation as late and easy as possible, which would allow for a different type of buffer inventory.

Other improvements would include the improvement of material flow to and from the factory, including inventory sizes, order sizes and the speed of parcels. Working ergonomy at the module assembly should still be improved by changing some of the tables. Optimum and universally standardized box batch sizes and thus table sizes and ergonomy could also be investigated.

11 Summary

This thesis aimed to improve the factory layout and the changeover timings of ACC Vantaa with Lean principles. The theory part explained the basics and practicalities of Lean thinking in order to be able to plan, design and later implement the improvements. A new layout plan was successfully created by improving upon the problems noticed with value stream maps, spaghetti diagrams and input from the team leaders. This plan was implemented with some changes, leaving space for further improvements. The new layout successfully improved changeover times of module assembly and cell operator work with the help of selected 5S improvements. The solution also provided much needed room for increased material inventory. By limiting the space available for pre-assembled modules the money bound on WIP was also decreased. It also gave the workers a clearer vision of the current status of production allowing faster feedback and cooperation.

Batch sizes and the flow of the production were not considerably altered except for the WIP limitation, whereas the layout change provides a clearer and more united structure, allowing flow improvements. Hopefully, the future will see increasing changes as more procedures and equipment are tested and continuous improvement is implemented more widely also in the incoming material flow. The functioning of 5S will require support and maintenance from supervisors until the habit is adopted.

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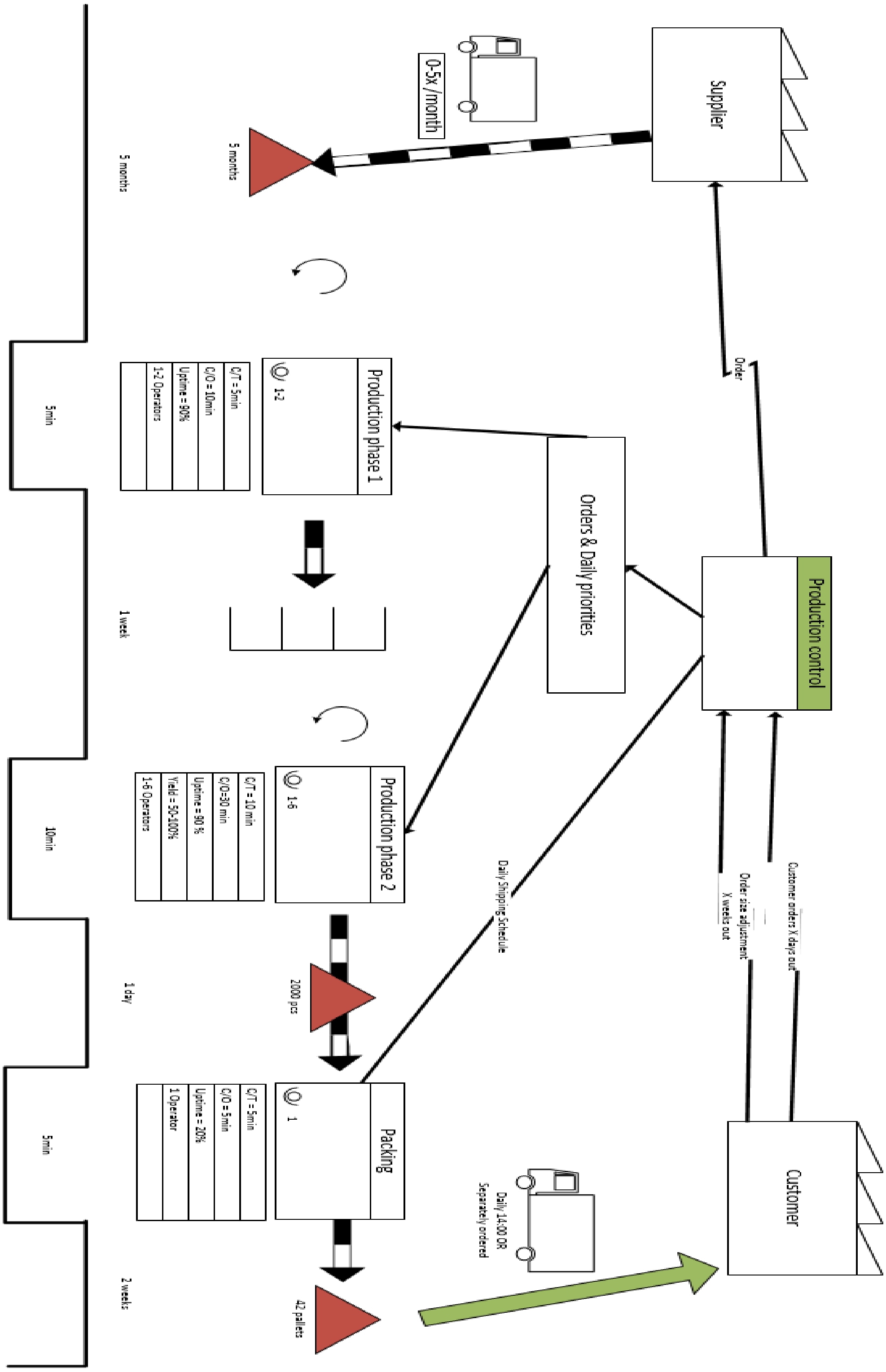
Appendix 1. Example Value Stream Map



Appendix 2. 5S Cell Sorting Results

Table 1, Work cell tools

Item	Frequency of use	Initial Amount	Final Amount
Markup tools	Frequent	1..4	2
Scissors	Semi-frequent	0..1	1
Post-it notes	Semi-frequent	0..3	1
Pliers	Frequent	0...2	1
Box cutter knife	Frequent	1..3	2
Screwdriver	Frequent	0..3	1
Powered screw-driver	Frequent	0..2	1

Table 2, Repair cell tools

Item	Frequency of use	Initial Amount	Final Amount
Painters tape	Rare	1	0
Scissors	Frequent	1	1
Post-it notes	Frequent	1	1
Wire cutters	Frequent	0...1	1
Markup tools	Frequent	1..4	4
Screw drive heads	Frequent	1..4	2
Stapler	Frequent	2	1
Box cutter knife	Frequent	3	2
Lamp	Rare	1	0
Drill bits	Rare	10	0
Torx screw drivers	Semi-Frequent	6	3

Appendix 3. Daily Management and 5S Visual Board Layout