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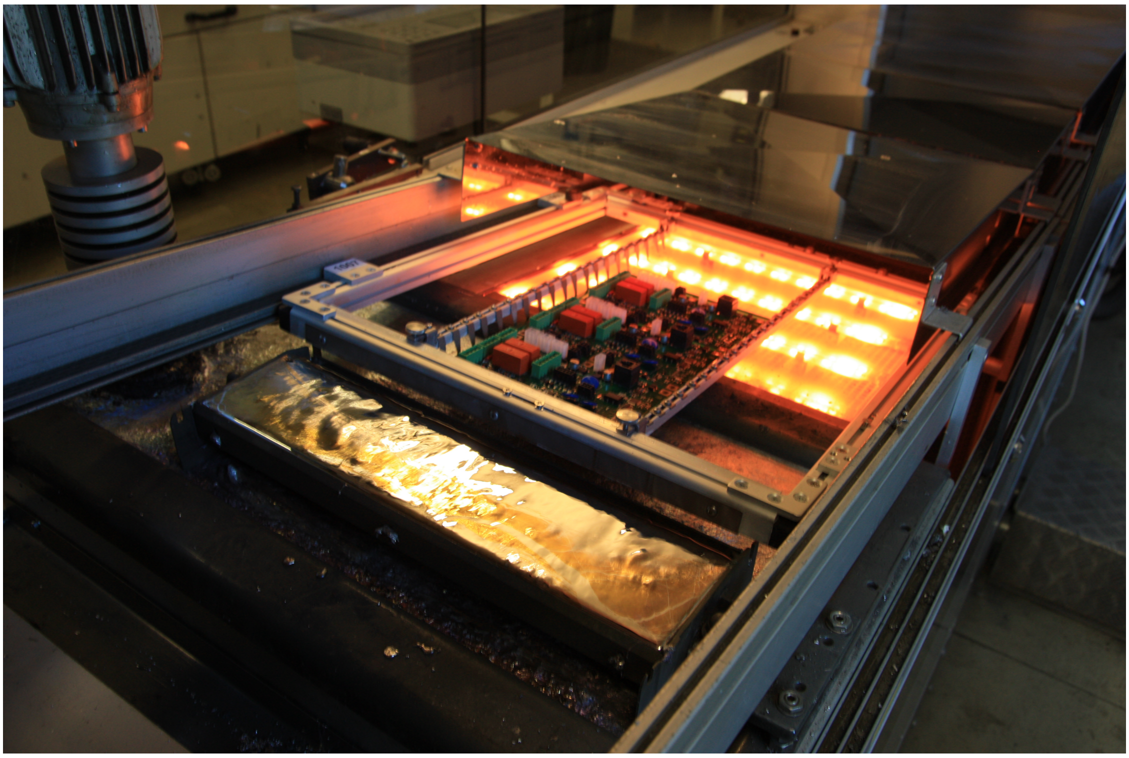

Improving Flow and Resource Efficiency to Increase Capacity and Area Utilisation

in Electronics Production

Master's thesis in the master's programme Production Engineering

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Department of Technology Management and Economics
Division of Operations Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015
Master's thesis E2015:060

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Cover: Product passing over the soldering wave in the leaded wave soldering machine

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Abstract

This master thesis has been conducted at Aros Electronics AB, a company producing electronic products. The thesis purpose was to increase the capacity of products that are being processed by wave soldering machines. At the start of the project, the production unit producing these products was highly process-oriented and this was considered to be the cause for a lot of waste in their production. Aros therefore wished to change their production system towards a more flow-oriented layout in order to reduce waste and create a more efficient production system.

In order to structurally analyse and improve the production unit, Methods Engineering was used. There were no obtainable time data for the products to be analysed so in order to to form a reference for the improvement work, work standards were created. The work standards were created through a time study using both Sequential Activity and Methods analysis and stopwatch estimations. In total, work standards for 15 products were constructed.

When creating a flow-oriented system, each products required work tasks need to be assigned to new work stations. This is done through balancing and was in this thesis made with the aid of a software named Avix, from Solme AB. The work standards of the 15 products where balanced and a new layout containing three new production lines where created. At this stage, a comparing analysis was also made in order to quantify the impact that Aros unstable production testing equipment has. Therefore, two balancing cases were made. One case, the ideal case, had 100 % uptime of the testing equipment. The second case, the realistic case, had time contributions added to the test equipment process times, based on the test equipment yields.
The realistic case was further analysed and resulted in a capacity increase of 87 %, a productivity increase of 192 % and a reduction of the occupied area of 23 %. The results could then act as a decision basis for Aros on how to move forward in their production development.

Keywords: Capacity, Productivity, Area utilisation, Electronic Industry, HMLV, Time Study, PTS, SAM, Resource balancing, Avix

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First of all, we would like to thank Kent Johansson at Aros Electronics AB for providing us with this opportunity. We appreciate that we have been able to wok independently through learn-by doing but with a constant knowing that help is always close at hand. The transparency we have been given within the production system of Aros has enabled a great understanding and knowledge of the dynamics of production systems.

We also want to thank the helpful staff of Aros production departments. Operators, flow technicians, material handlers and service personnel and all who have aided us in our understanding of the production processes. We especially want to thank all the operators in the Green Production Unit for taking their time to be filmed, patiently answering all of our questions and for being generally supportive and showing interest in our project.

Our sincerest thanks goes to Kent Johansson, Marie Staberg-Nyqvist and Fredrik Andersson for their support and guidance. Thanks also to Oskar Ljung and Glenn Heiman at Solme AB, for giving us licenses to the Avix software and for helping us when we ran into problems with it.

Finally, we would like to thank our supervisor and examinor Peter Almström for his guidance throughout this project. His quick responses when we needed help and the ability to concretise complex, to us, problems have been deeply appreciated.

Lina Jansson Linda Stridsberg, Gothenburg, June 2015

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1
Introduction

Aros Electronics AB is the provider of this thesis project. In this chapter, firstly the company and their production systems is described. Then follows a description of the project background, problem formulation and limitations.

1.1 Aros Electronics AB

Aros electronics AB is an Mölndal-situated company that develop, design and manufacture customised electronic solutions for industry applications. They are specialised in the field of electrical motor drives, sensors and field bus technology. Aros has since 2001 been a part of the textile industry-based Van de Wiele group. In 2012, Aros was merged with the IRO AB concern who produce and develop products within the textile industry.

Van de Wiele group is an international company with main focus on developing and producing textile industry machinery, for example carpet-and velvet weaving machines. Van de Wiele headquarters lies in Belgium but the group has 14 facilities placed worldwide, which in total employs roughly 2500 people and has a net turnover of roughly 400 M EUR. Their facilities are placed in Sweden, Belgium, Germany, Italy and China (Aros Electronics AB, 2014) (Van de Wiele group, 2012).

IRO AB is a developer and manufacturer of textile products who specialises in yarn feeders (IRO AB, 2014). They are located in Ulricehamn, Sweden, and in 2013 they employed 102 people and had a net turnover of 270 MSEK. (allabolag.se, 2015).

Aros Electronics AB was founded in 1970 and has in recent years seen quick and steady growth. In 2013, Aros had 119 employees and a net turnover of 250 M SEK. Since Aros joined the Van de Wiele group and merged with IRO AB, they have expanded within Sweden and to Belgium, China and Italy. They provide customised electronic solutions for companies in industries such as the automotive, textile, heavy equipment and electronic. Aros has a wide range of customers but the most well known are Volvo, ABB and Caterpillar.

In the Mölndal production site Aros has development, design and production all under the same roof. This is one of Aros strengths since it makes for easier communication between the different departments, short lead times, cost efficiency and thorough quality control. Due to the customisations that Aros offer their customers, there is a great mix in products in production and a wide range in product complexity. They produce everything from small circuit boards to fully integrated customer-unique systems such as motor drives for air compression systems in buses.

1.1.1 Aros Production System

The production system of Aros consists of a variety of both automated and manual processing steps. For example, they have manual assembly stations, automated pick-and place machines, wave soldering machines, selective soldering machines and coating machines. The production is divided into four main production units, categorised by colours, which are: Yellow unit, Orange unit, Green unit and Blue unit. See figure 1.1 for a complete description of Aros production system.

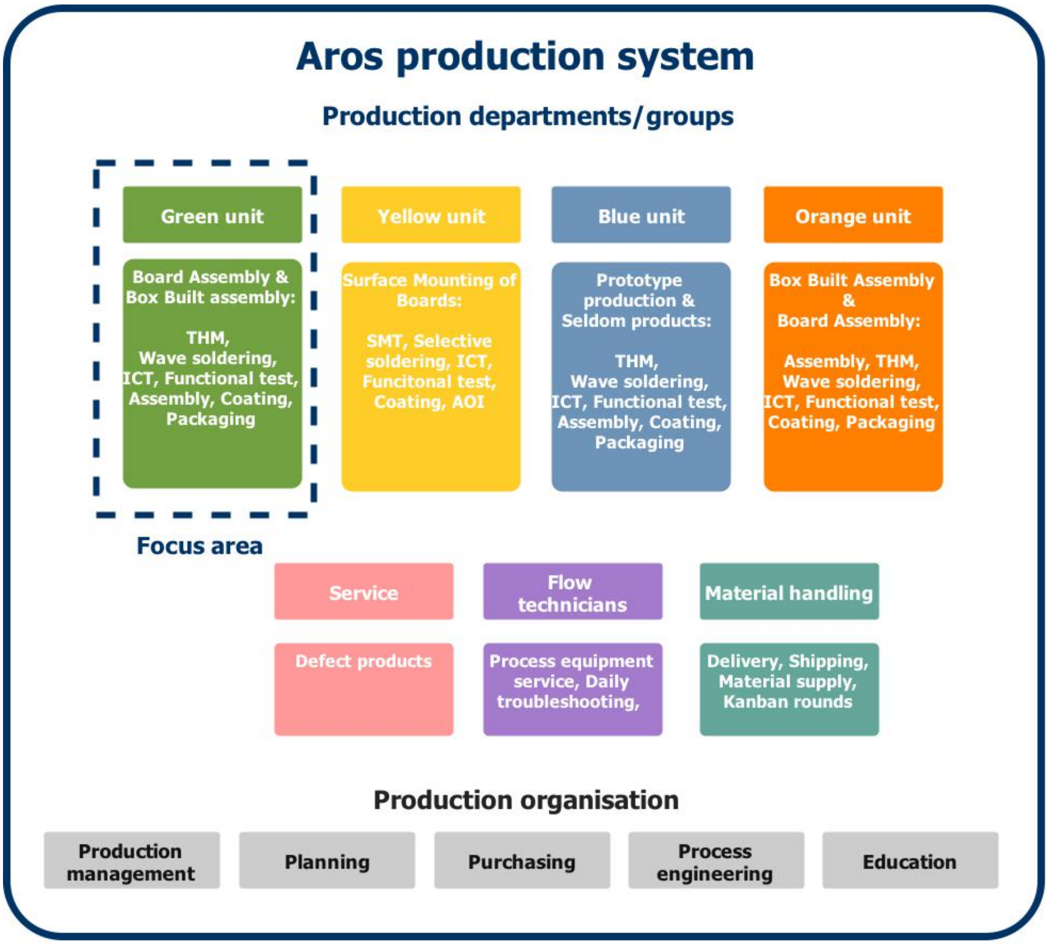

Figure 1.1: Project focus area

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Yellow unit
Yellow unit is run in two shifts, a day shift and a night shift. It is operated by 20 operators and one production leader, responsible for different shifts and parts of Yellow units production. The Yellow production unit is highly automated and

consists of a surface mounting technology (SMT) line with pick and place machines, reflow ovens and automated optical inspection (AOI) machines. After the SMT line, the flow of products splits up into either the selective soldering line or continues to the other production units. The selective soldering line consist of a selective soldering machine, a coating machine and testing equipment. Products from the selective soldering line mostly go to Orange production unit but some products also go to the Green production unit.

Orange unit
Orange unit consist of 22 operators and one production leader. This production unit mostly make box built assemblies for integrated solutions. They also have a few products that they through-hole mount (THM) and send to the wave soldering machines. They also perform testing for their products and some testing equipment is shared with Green production unit.

Green unit
Green unit consists of 18 operators and one production leader. The production unit mostly produce products that go through the wave soldering machines, which then need testing and board assembly. However, they also have responsibility over some products that do not need the wave soldering machines but require manual soldering instead. These products are then processed in the same manner as the others, with box built assemblies and testing.

Blue unit
Blue unit consist of 8 operators and one production leader. They manufacture seldomproducts with high fluctuations in demand. The demand can be either from new products that are not part of the reoccurring demand or they can be old products that are sold in low volumes. Most of these products require the wave soldering machines.

Material handling
Material handling are responsible for deliveries, shipping and supplying the units with material and components. Aros has attempted to implement a scheduled Kanban system. Material handling staff should make four rounds each day to fill up material on the workstations and retrieve empty material containers. Some material has to be replaced from its original packaging into smaller boxes before transportation to stations and this responsibility belongs to Material handling. For some products, material handling has to collect finished products on the stations but most finished products are placed in a finished goods section in the Material handling area.

Service
The service unit looks into problems with defect products that are too complicated for the operators to resolve and they aid in all three production units. **Flow technicians**
The flow technicians roles are diverse but mainly they make sure production processes are running as they should. Also, they solve daily problems with everything

from changing light bulbs to repairing broken equipment.

1.1.2 Production flow through the production units

Figure 1.1 shows an overview of of how production flows between the different production units.

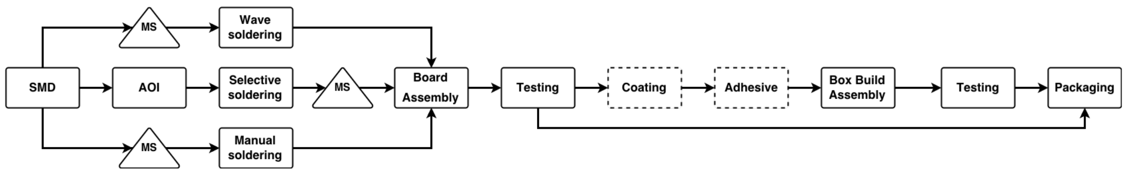

Figure 1.2: Overview of the production flows between production units

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1.1.3 Green production unit

At present, Green unit is in charge of producing roughly 26 reoccurring products. The products are similar in their required processing steps but the steps themselves vary a lot in length and sequence.

The production is highly process oriented and each operator in Green unit follows one product from start to end and has complete assembly responsibility. The operators in Green production unit work in cells were they are responsible for everything from visual inspections, assemblies, coating, functional testing of products to packaging of products. The work is mostly performed in large batches and work rotations are seldom made. An exception to this is the so-called Albany-line, where a line flow has been attempted to be implemented. Here, five operators on five different workstations work on a few products, that have a high volume demand and are very similar in the processing steps

.

Production planning:
Each new week starts with the production leader distributing the weekly workload, the production plans, to the operators within Green unit. This distribution is based on which products are to be produced, what volumes they come in and the available workforce.

The production plan is a product specific document that contains the weekly volume to be produced, all processing steps required to produce the product and which components and materials are needed. The volumes in the production plan is based on an internal takt document called Takt-data. Takt-data is a document that is compiled once each month by the production planning department and is based both on forecast and actual orders from customers.

The production plans should ideally be followed but adjustment during the week occurs. Common reasons for this are:

- Failures in meeting delivery times. Making some products be down-prioritised and their production is postponed.
- Lack of workforce.
- Process equipment failures.

In conclusion, production planning on weekly level is based on estimations from the production leader. The production leader has knowledge and understanding about the processes, the operators and the process equipment and makes production planning based on these three aspects. Production planning on higher levels are based on forecasts and actual demand.

1.2 Project background

Aros has gone through rapid developments from being a small-size manufacturing company to a medium-size manufacturing company and their current production strategy is no longer suitable. At present, they are highly space limited and need to increase their productivity in order to raise their capacity level. Green unit is considered to have especially high potential in increasing productivity since the production in this unit are at present oriented towards processes rather than a flow. Another problem are unstable processes in the system and these are especially connected to the different testing equipment. Due to these facts, the lead times are unnecessary high, buffer levels are necessary and take up space and it is difficult to maintain delivery precision.

1.3 Problem definition

Aros are in need to change their production system in order to increase their capacity. They wish to use the results of the thesis as a decision basis on how to move forward in their production development. The purpose of this thesis is therefor to explore, through resource balancing, different options for Green unit to go from a process-oriented system towards a more flow-oriented system. The main goal of the proposed suggestion is to create space on the production floor and increase productivity.

1.3.1 Research questions

This thesis aims to investigate the following research questions, where the percentage goals have been set by the production management of Aros.

- Is it possible to increase Aros production capacity of a specified product mix in Green production unit by 50% if going from a process layout towards a flow oriented system? If not, which level can be reached?
- How much can the occupied area for the specified product mix in Green production unit be decreased when creating a flow oriented system?

1.4 Delimitations

A main limitation of this thesis is that only the production flows linked with products using the wave soldering machines will be analysed. Green, Blue and Orange unit are connected to the wave soldering machine.

- The balancing of operations will be performed on all tasks related to products manufactured within the Green unit but not the task related to Blue or Orange unit. Products from Blue and Orange unit will be taken into consideration if changes in the physical environment should impact them but they are not part of the balancing.
- The analysis will start from when components arrive to the Green unit until they are packed and ready for delivery.
- Process technology and other heavy investments for Green unit will not be made. The analysis builds on maximising the utilisation of available resources in operators, machines and the facility itself.
- The balancing will be focused on increasing productivity and creating more space. Aspects such as quality, ergonomics and costs will be considered but not be the primary focus.

2
Methods

This chapter will describe the methods used during the project. It will describe the procedures used both for the more practical work on the production floor as well as the more theoretical. Firstly, a pre-study was conducted to gain knowledge about the topic and Aros. From this it was concluded that the general approach of Methods engineering would provide a good foundation for this thesis method, since it suited well with the thesis scope.

This chapter will therefore firstly present the pre-study method. It then continues to describe the work procedure of Method engineering and finally, it will connect each of the procedure steps in Methods engineering to the work performed during the course of the thesis.

2.1 Pre-study

A pre-study was conducted in order to gain sufficient knowledge about the topic of the thesis and the company, since both authors had no prior connections to the company or the electronic industry

2.1.1 Work Practice

Since the authors, as previously stated, had no previous connection to Aros, an introduction program was provided from the supervisor at Aros. This enabled the authors to quickly gain knowledge about Aros and its company structure. Most of the time during the introduction program was spent on work practice within the Green production unit to gain sufficient understanding about the processes. The work practice lasted seven days and the work days where split in half so two products per day could be covered. By doing so, as many processes and products as possible was either observed or experienced in practice. The work practice also made the authors getting to know the operators within the Green unit, which made communication during the project easier. It also gave a rough idea of the problems present at the production floor.

2.1.2 Literature review

The literature study has been carried out throughout the project but with its main focus at the beginning of the thesis. At the project start, literature connected to each phase of the project that was considered to be of use was collected and reviewed to gain a deeper general knowledge. Once a new phase in the project has been entered, literature connected to it has been covered again to ensure nothing has been forgotten or misinterpreted the first time. Also, additional information and topics has been covered that was not known at the start that they would be needed.

Since the aim of the thesis is to increase Aros production capacity by changing their production system from a process-oriented system towards a flow-oriented system, with a main focus to create space and increase productivity, the reviewed literature has been connected to this. Keywords used when searching for literature have been: work standards, work measurement, capacity, methods engineering, SAM, balancing, production systems.

2.1.3 Data review

This thesis is a continuation of a time study project that a former employee at Aros started, where the processing steps of a few products in the scope had been video recorded. These videos were reviewed to see which products and processing steps that had been recorded, so that the authors would be able to save time. Next, the processing steps and work tasks of the videos had to be confirmed with the operators. This was done to ensure that the videos contained up to date information.

2.2 Procedure of Methods engineering

When performing any change project, it is a good idea to follow a set procedure that is set clear to everybody involved before any activity is started. This will then result in the below following benefits from (Zandin, 2001, c. 29).

- It is possible to ahead of time get a good project understanding among all the people involved.
- Improvement activities will be more efficient and wasted effort can be avoided.
- By concentrating on the step at hand, the quality of work done for each step will increase.
- Monitoring of progress can be readily done.

For Methods engineering, the set procedure has already been formalised into below eight steps(Zandin, 2001, c. 29).

Step 1: Define the scope
Consist of two sub-steps:

1. Decide what needs to be improved, select a goal
   In manufacturing typical goals are to improve labour productivity, equipment productivity, reduction in inventory, reduction of lead times, level out production demand, improved ergonomics or balancing a system.

2. Decide area to be studied, select a study subject
   Could be a department in the factory, a production line, a process in a complex manufacturing operation etc.

Step 2: Set the targets
At this stage, the goals to be achieved are set and the project specification decided. To do this, first a general data collection concerning the study object is completed. Data to collect include for example past production volumes, allocated personnel, items produced, equipment and material needed and the variety of finished products produced.

Also at this stage, any constraints to the project needs to be clarified along with any design specifications. Design specifications could be regarding production capacity, products to be handled, throughput time and quality standards.

Step 3: Doing the analysis
In order to improve or redesign a system, the current conditions must be thoroughly understood and analysed in order to find root causes for problems that must be improved (Zandin, 2001, c. 29). In this work the following points are important to follow(Zandin, 2001, c. 29):

- Take a quantitative approach as much as possible
- Analyse to a level of preciseness adapted to the subject being analysed (not too coarse, not too detailed).
- Present results visually (make good use of charts, graphs, and drawings).

In doing this, the industrial engineer have many established analysis techniques to choose from. Commonly used methods are for example process analysis, operation analysis, motion study, time study, work sampling and flow analysis.

Step 4: Modelling the area to be improved
Many factors impact the production system and its performance varies on daily basis due to a variety of factors. The factors could for example be related to work methods used by operators, conditions of resources and quality of parts. In order to conduct improvement work in an efficient manner, it is important to model a representative model of the system. The model should be based on the most typical values and status of the system. Improvement work should then focus on the values defined in the model and not be distracted by daily fluctuations in the real production system (Zandin, 2001, c. 29).

Step 5: Developing the ideal Method
Once the model has been created, the improvement plan should be made. This plan will vary, depending on the objective set for the improvement activity in step one. If the activity is improvement of work methods performed by the operators, the project will take one route. HOwever, if the improvement activity is the structure of complex multiprocess system, another route will be necessary (Zandin, 2001, c. 29).

When the change project involves changes in multiprocess system, which this thesis project does, the first step is to study the relationships between the various processes (Zandin, 2001, c. 29). The main task at this stage is to evaluate the suitability of different production strategies. Consider and compare line production methods with cell production methods or individual production methods. Also, if the production should be in continuous flow or batch orientated. And in the case of line production, the type of line should be considered. It could be a variety of product models on a few lines, or a limited number of models on multiple lines(Zandin, 2001, c. 29). Other aspects to consider, if changes to layout are considered, are how these will affect other aspects. Aspects such as material handling methods, production control and work in progress (WIP), who all have big impact on the production systems output.

To aid in this analysis work, there are many different analysis tools that can be used and below follows a list of some of them.

- Eliminate, Combine, Rearrange, Simplify (ECRS)
- Principles of Motion Economy
- Brainstorming
- The 5W1H Method

Step 6: Selecting the improvement plan
Selecting the best option, from several available ones, should be based on uniform evaluation standards where the cost, time and technical difficulties of the improvements work should be considered. Basically, all aspects considered in the objectives for the improvement work should be included in the evaluation(Zandin, 2001, c. 29). Parameters evaluated, both qualitative and quantitative, should to as much extent as possible be given target numbers prior to the beginning of the evaluation. This to more easily determine which suggestion is the best. Usually the the different aspects are given different weights, which then helps determining the solution with the highest impact potential. There are several standard methods to choose from at this stage and two possible ones are the Kesselring matrix and the Pugh matrix.

Step 7: Implement new systems
In implementing the new system or method, much preparation is necessary. It involves everything from ordering to installation, educating and training operators, creating user manuals and setting maintenance procedures(Zandin, 2001, c. 29).

Step 8: Follow up and enforce new methods
Once the new system is in place, it is important to follow up and monitor the systems performance in order to ensure performance at target levels. As a mean to achieve this written standard, operating procedures and work standards should be made and maintained as well as standard procedures for equipment maintenance. As a way to ensure that the new systems is performing at target, the implementation of measurement system is necessary (Zandin, 2001, c. 29).

2.3 Step 1: Define the scope

This step has already been defined by Aros and is the reason for this thesis projects existence.

Selected goal of study:
To improve the capacity by balancing the production system as well as reducing the occupied area of the subject of the study.

Selected study subject:
The products of Green production unit that are being processed by the wave soldering machines.

2.4 Step 2: Set the targets

The targets to be reached were decided before the data collection started. This was done by the production management and was formulated into the research questions. Also, limitations to the project were done and these are formulated in the delimitation in the introduction chapter.

The data collection performed was extensive and its results can be seen in the Current state chapter. Data was gained through internal documents of the company, own measurements, the Enterprise Resource Planning system (ERP), T-Log (internal Performance Measurement System (MPS)) and many discussions with operators. The data was collected in the following areas:

- Product related data
- Area related data
- Test data
- Process equipment data

2.5 Step 3: Doing the analysis

In order to find the root causes to the capacity issue, a cause and effect analysis was made. This showed that many of the problems origin from the lack of time data and work standards. It was therefore concluded that work measurements were needed in this project.

There where no time data available for either process equipment nor manual handling. Capacity data for process equipment was collected trough stopwatch measurements and the internal MPS T-log. The results from this can be seen in the Current state chapter. The analysis of which data to use as the standard time data is however presented in the Analysis chapter.

Due to the manual work being repetitive, a time study was chosen to be the appropriate method for determining standard times for manual work activities. The standard times were mostly done by using Sequential Activity and Methods analysis (SAM), an easy to use Predetermined Time System (PTS). It is recommended to start a time study through stopwatch analysis but in order to do method improvement simultaneously when doing the study, a PTS system is more convenient. The reason for this is that micro motions and moving patterns of operators and material become more visible and easier to eliminate during this type of analysis.

Since the work tasks were a mix of short, medium and long, SAM was not always the best option. Therefore, when a task was medium to long or when the task had motions that were difficult to analyse, stopwatch measurements were also used. All work tasks have been video recorded in order to later judge the best work measurement. By video recording the operator, all work tasks required to perform a processing step was documented in an accessible way. Also, this enables any disturbances to easily be subtracted when later analysing the video. Each film covered between one to three complete work cycles to ensure that different variations are caught on video. The Avix software was used since it provides good visual aid and supports resource balancing, which is the final aim of the thesis. The results of the time study can be seen in the Analysis chapter.

2.6 Step 4: Modelling the area to be improved

The time standards developed in previous step now became the foundation for a representative model of the current systems, although work improvements have already been implemented. Each products work cycles for the processing steps could be added to each other to form an estimated lead time per product. The lead time for one product was verified through a live-test. The results for this can also bee seen in the Analysis chapter.

In an attempt to model the current production systems, lead time were estimated for the specified product mix. The team leader who is responsible for the daily plan was asked to plan the production for Week 19, based on her own knowledge of the process, which is the way production is normally planned. This became the time reference to be used when later comparing the results from the improved state.

2.7 Step 5: Developing the ideal Method

As stated multiple times, the objective of the thesis was to improve the capacity by changing the production layout to a more flow oriented layout. Product families where therfore made, with the use of production flow analysis (PFA) of the already created product and process map. Each product family was then balanced individually and with the use of ECRS, work tasks were attempted to be eliminated, work stations combined, products routing rearranged and general routing simplified.

The balancing was performed with the resource balance module in Avix. The first step in the balancing was to define the objective. In this case, the project goal is to increase capacity and reduce the occupied area through a flow-oriented system. When balancing, the objective therefore was set to minimise both cycle time and number of workstations in order to increase efficiency of both flow and resources. The balancing results can be seen in the Solutions chapter.

Once the final balancing suggestion had been established, each work stations work tasks where evaluated with regards to how much space they now would required. From this, the improved layout suggestion could be made to illustrate the area reduction as well as the new product flows.

The Capacity of the improved state was calculated as the maximum product output during a week of production and then compared to the current state Capacity. This definition of Capacity does however not say much about the impacts of the suggested flow-oriented system. Therefore, a Productivity increase estimation was made in order to show the impact of methods improvement and to show the effects of focusing on both flow and resource efficiency.

2.8 Step 6: Selecting the improvement plan

Since the aim of the thesis work was to present only a suggestion of how to increase productivity, by changing their production strategy to a more flow oriented system, this step lies outside of the thesis scope.

However, the presented suggestion should at this stage be weighed against the other options that Aros has. For example, one option they have is to entirely phase out the use of the wave soldering machines and use selective soldering instead.

2.9 Step 7: Implement new systems

This step is also left to Aros to perform by themselves, once an improvement plan has been chosen and a production strategy finalised. The authors has however proposed some implementations suggestions in the discussion chapter of this report, if Aros decides to implement the suggested solution.

2.10 Step 8: Follow up and enforce new methods

Also for this step some suggestions will be aired in the discussion chapter of the thesis.

3
Theory

In this chapter, the theory of the tools and methods that has been used in the thesis will be presented. Firstly, research about capacity and productivity will be presented. The chapter is then followed by some background information regarding the general method applied. After that, the theories regarding production layout and balancing and their related impact will be reviewed. Also, a chapter about lean production has been included since Aros is influenced by this management system. Lastly, some basic information about the software used in the thesis will be given.

3.1 Capacity and Productivity

In this section, the terms capacity and productivity will be explained and defined.

3.1.1 Capacity

According to (Olhager, 2013), capacity should be defined as the maximum work output that a given production resource can produce during a given time period. The work output is given as the maximum capacity of work time during a period of for example a 40 hours week or an eight hour shift.

Capacity can also be measured as maximum product output during a given time period but (Olhager, 2013) states that this is misleading and does not tell much about the true capacity. This since most products in a production system differ from each other and hence has different process flows and times that need to be considered. Capacity can hence be measured either by equation 3.1 or 3.2.

$$Capacity = \frac{Maximum\ Work\ Time\ output}{Given\ Time\ Period\ input} \tag{3.1}$$

$$Capacity = \frac{Maximum\ Product\ output}{Given\ Time\ Period\ input} \tag{3.2}$$

3.1.2 Productivity

Productivity is a term that can be used with many definitions but simply explained, it is a measure that is used to show the output from a system compared to the input of resources to a system. Equation 3.3 is one way of measuring productivity and according to (Sakamoto, 2010), it is the measure that is most commonly used.

$$Productivity = \frac{Product\ output}{Labour\ input} \tag{3.3}$$

According to (Sakamoto, 2010), productivity can also be measured with inputs as money, number of workers, materials, energy. So it is of high importance to define a correct productivity measure for the system that is to be analysed.

As mentioned, output in relation to labour time input is a common measure. However, this measure can and should also be developed and used as a more complex measure in order to reach higher productivity rates (Sakamoto, 2010). By separating the measure into the three factors according to equation 3.4, an organisation may receive a better perspective on what impacts the productivity and what to focus on.

$$Productivity = M \times P \times U \tag{3.4}$$

M=Methods
This factor represents the planned for productivity rate or ideal cycle time.

P=Performance
The performance factor has to do with both operator speed and speed of process equipment. It gives a percentage of how fast a resource is working in relation to the planned production time or ideal time.

U=Utilisation
The utilisation factor also concerns both people and equipment. The utilisation factor is denoted as the time spend on value-adding work as a proportion of the planned production time or ideal time.

3.2 Background of Methods engineering

Since the the thesis involves performing a time study, it became apparent through the literature study that the general method approach of Methods engineering would be appropriate to adopt. Below follows a short introduction to Methods engineering and its definition. It is good for the understanding of how Methods engineering and time studies are closely related, with no clear boundaries between them.

3.2.1 History Methods engineering

Time standards and work study origins from the late 1800s when Fredrick Winslow Taylor, a foreman at Midvale Steel company, wanted to increase productivity at his production department. His attempts were based on systematic analyses of operations and in time his analyses led to the principle of: "The greatest production results when each worker is given a definite task to be performed in a definite time and in a definite manner"(Stegemerten and Schwab, 1948, p.6). During the same time period, Frank Gilbreth, a former building contractor, and his wife Lillian

Gilbreth was performing motions studies of work in order to improve work methods. Franks interest of the subject started on his first day as a bricklayer apprentice when he discovered that the simple task of laying bricks could be performed in numerous ways. The Gilbreth's performed detailed laboratory studies of motions and methods and developed the micromotion study procedure that still forms the basis of the first PTS (Stegemerten and Schwab, 1948, p.6).

Between the years 1910-1930, the two fields of study was considered to be total opposites of each other where the time study group could not see the use of the laboratory approach. And the motion-study followers thought of the time study groups work as unscientific and crude(Stegemerten and Schwab, 1948, p.7). Once the two sides became more familiar with each others work they realised that they had been working on the same subject, just calling it by different names. The best features of each approach where brought together to form the basis of a new, single universal applicable approach now known as Methods engineering (Stegemerten and Schwab, 1948, p.7). In short, Methods engineering can be described accordingly:

"Methods engineering is a systematic technique for the design and improvement of work methods, for the introduction of those methods into the work place, and for ensuring their solid adoption"(Zandin, 2001, c.29).

In the beginning, the objective of Methods engineering was to improve already existing work systems. This however changed and later a more design-oriented approach has begun to evolve. The new approach can be applied in developing and designing a completely new system, not existing before (Zandin, 2001, c. 29). A shift in the focus on the improvement of systems have also occurred during the years. Initially, the focus was mostly on individual work with high content of repetitive operations. This has later changed to look at more complex systems and improve it as a whole, involving also people and equipment(Zandin, 2001, c.29). Because of this shift, the objective of Methods engineering has also gone through a change. From the objective originally being limited to increasing productivity, it now contains a wider purpose of improving work system flexibility, expandability and maintainability(Zandin, 2001, c.29). It has today evolved so far as to involve more softer topics. Softer topics are for example improving customer satisfaction, improving ergonomics and improving safety and creating a more comfortable work environment(Zandin, 2001, c.29).

3.2.2 Definition of Methods engineering

During the evolution of Methods engineering, numerous definitions of the subject has developed. The thesis will use the definition presented in (Zandin, 2001, c. 29), which in turn is is taken from the 3rd edition of Industrial Engineering Handbook:

"The technique that subjects each operation of a given piece of work to close analysis to eliminate every unnecessary element or operation and to approach the quickest and best method of performing each necessary element or operation. It includes the improvement and standardisation of methods, equipment, and working conditions:

operator training; the determination of standard time; and occasionally devising and administering various incentive plans." (Zandin, 2001, c. 29).

The thesis will however widen the perspective compared from the definition. Instead of just analysing the given work piece operations, the whole production department of the Green unit will be evaluated including its equipment and people.

3.3 Time study

As stated in the methods chapter, the results of the thesis relies on work measurements based on time standards. Below follows the the most important theory on this topic.

3.4 Work measurement

In order to make manufacturing operations as efficient as possible, systematic analysis of work and the establishment of work standards is required (Zandin, 2001, c. 29). According to (Zandin, 2001, c. 29), there are three main methods for measuring work and developing time standards.

3.4.1 Estimations

Estimations is one of the methods and can be made in two ways. Either a person with knowledge about operations makes experience and knowledge-based time estimation of them. This estimation method does not properly consider the variations in operation time and can lead to missed schedules and bottleneck creations. The other way is to base estimations on historical production data. Historical data over previous production times and quantities can though give cause for the Parkinson's law, which states that work will expand to fill the available time (Parkinson, 1957)(Zandin, 2001, c. 29).

3.4.2 Direct observation and measurement

Direct observations can be made in three ways: Time study, Work sampling and Psychological work measurement. Time studies are conducted by recording the time of performing an operation, study the method, rate operator performance in comparison with normal pace and adding allowances for Personal needs, Fatigue and Unavoidable delays (PFD). Time studies are appropriate when tasks are repetitive and relatively short cycled. When work cycles are long, work sampling is more appropriate to use. Work sampling is a statistical technique that gives a prediction of time consumption for activities through making a large number of observations at random intervals. Psychological work measurements is used to measure physiological costs of workers performing tasks. For example, a beginner at a certain task has a higher physiological cost then an experienced operator, if attempting to perform at standard rate(Zandin, 2001, c. 29).

3.4.3 Standard data systems

Standard data systems are collections of motion time data that have been compiled from previous studies of manual work. Standard data system can be divided into two types: Macroscopic and Microscopic standard data. Macroscopic time data is based on similarities in work elements between operations. These similarities in work elements are developed to time standards for these activities. Microscopic standard data, also called PTS, are used to decide on standard times through detail studies of every single motion needed to perform a job. The time required for the motions are found in PTS and through analysing single motions, whole sequences and their required time can be constructed up(Zandin, 2001, c. 29).

3.5 Predetermined Time systems

There are many types of PTS but they all require the same thing: an extensive understanding of the studied operations and a complete definitions of all single motions involved. The time required for the single motions can be summarised into a total operation time and the PFD-allowances can be added to create a defined standard time(Zandin, 2001, c. 29).

3.5.1 MTM

Methods-Time Measurement (MTM) was the result of the need for being able to measure work methods and time simultaneously, instead of separately as they were made previously. The definition of methods engineering according to (Stegemerten and Schwab, 1948, p. 7) states that a work method should be developed, standardised and taught to the operator, in that order. The work time should be measured only after the work method had been taught. (Stegemerten and Schwab, 1948, p. 7). This proved to be difficult in practice since better methods are sometimes found during time studies. Therefore, it was difficult to decide on which method is the best, without making a time study first. MTM solves this problem since it makes it possible to analyse both method and time simultaneously (MTM-föreningen i Norden, 2015b).

The MTM system originally was one system but over the years, updates to the system were brough and there now exists three versions of the MTM-system (MTM-föreningen i Norden, 2015a).

- MTM-1. This is the original MTM-system and contains all original motion and time data that the other two versions are based on.
- MTM-2. MTM-2 is a development that was presented in 1965 and this system is used for more simple motions than those requiring MTM-1 (MTM-föreningen i Norden, 2015a).
- MTM-3. MTM-3 came after MTM-2 and is an even more simplified version (MTM-föreningen i Norden, 2015b).

All PTS systems has a standard time unit that all motions are given in values of. The standard time unit of the MTM systems is called TMU, Time Measurement Unit, and one TMU is equal to 0.00001 hours (Zandin, 2001, c.126).

3.5.2 Sequential Activity and Methods analysis

SAM is a system that originates from MTM and built up on the same basis as MTM 2 and MTM 3 and it has an accuracy that lies in between MTM 2 and MTM 3. It is created on a base of sequential thinking and during its development, the aim was to create a system that can be used in communication with operators, designers and processing/preparation departments (MTM-föreningen i Norden, 2015b)
.
The SAM-system is based on a time unit called a factor. One factor is equal to 5 TMU:s (IMD, International MTM Directorate, 2004).

SAM builds on the fact that manual motions involving objects, follows an activity sequence of getting an object and putting the object into a final position.

There are three type of activities in the SAM-system:

1. Basic activities
   (a) Get
   (b) Put
2. Supplementary activities
   (a) Apply force
   (b) Step
   (c) Bend
3. Repetitive activities
   (a) Screw
   (b) Crank
   (c) To and from
   (d) Hammer
   (e) Read
   (f) Note
   (g) Press button

Some of these variables in turn has variables that they depend on. Variables for put are for example Movement distance, Weight and Degree of precision.

The variables are also divided into different levels, so called classes and cases. The classes for the movement distance variable are three and they are defined as the distance the hand is moved. The classes are up to 10 cm, between 10-45 cm and 45-80 cm, including a supportive step. After 80 cm, including the supportive step, supplementary activity step needs to be added.

To conclude, the standard time for an activity sequence is then based on the three main activities, their variables, cases and classes (IMD, International MTM Directorate, 2004).

3.6 Production flow strategies

”Production flow refers to the movement of the product through a facility” (Zandin, 2001, c. 112). By effectively managing the production flow, product throughput and quality can be increased. Also, inventory, lead times and material handling can be reduced, which provides competitive advantages for the company. There are four main categories that affect the production flow (Zandin, 2001, c. 112):

1. Product
2. Product environment
3. Facility layout
4. Operational strategy

The product and customer demand restricts some choices but many factors can still be controlled by the company (Zandin, 2001, c. 112). Focus in this literature review will lie on facility layout since that is most closely connected to the topic of the thesis.

3.6.1 Facility layout

The facility layout is of great importance in how efficient a production plant is. The production flow depends largely on how well its resources, equipment and employees, are distributed around the production floor. In a properly laid out plant, the movement of material from raw material to finished product is smooth and rapid. The movement should preferably be in a forward direction with no crisscross movement or back-and-forth transportation between operations (Aswathappa, 2011). There is however no set pattern of how a facility layout should look like. Every facility is different and the layout depends greatly on product size, product variety, production volume and production flexibility (Zandin, 2001, c. 112).

Production is a living environment and an optimal layout at one point might not be so further down the road, therefore the initial layout is almost never final or permanent. There are five basic types of layout, which managers can choose to implement: Continuous flow layout, product layout, process layout, cellular layout and fixed layout, see figure 3.1. Each type is described in more detail below (Zandin, 2001, c. 112).

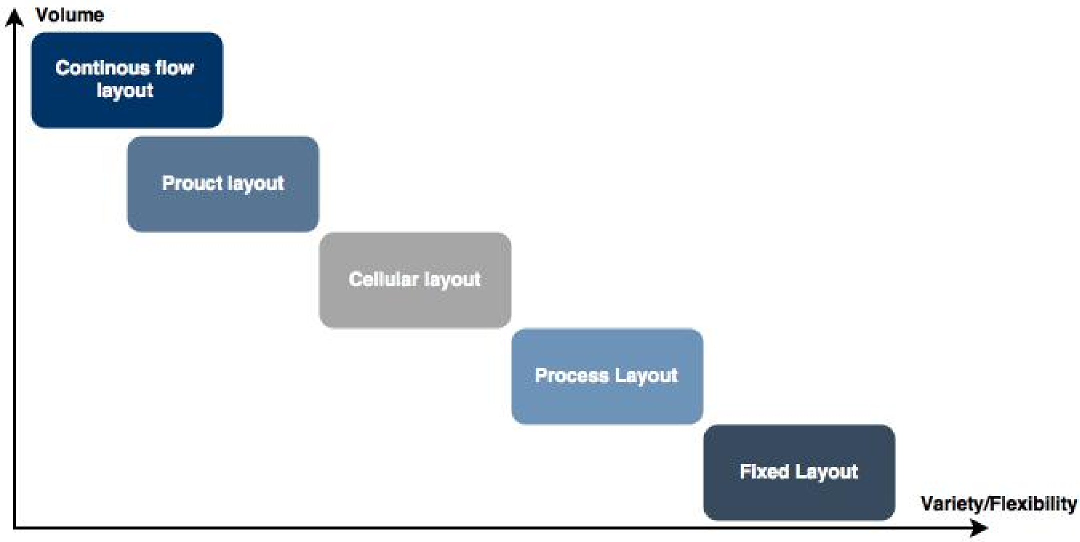


Figure 3.1: Correlation between volume and flexibility

3.6.2 Continuous flow layout

Continuous flow layout is usually adopted in the processing of non-discrete materials such as fluids or bulk material(Zandin, 2001, c. 112). Hence it is not a single work piece being moved around but it is rather the storage container that decides the size lot (Zandin, 2001, c. 112). All material goes through the same processes in the same sequence.

3.6.3 Fixed position layout

Fixed position layout is, just as the name indicates, used when the products are difficult to move due to size and weight. The material, tools, machinery and workforce are therefore brought to the fixed position of production(Kachru, 2007)(Zandin, 2001, c. 112). Highly skilled workers build the product according to detailed customer specifications and the quantities often equal one (Zandin, 2001, c. 112). Since there is no product flow, focus on organising workers in teams and creating zoned areas within the production is essential in order to have a high efficiency (Zandin, 2001, c. 112). Also, good planning and focused attention on critical activities is therefore essential in order to maximise margins (Kachru, 2007). The main advantages and disadvantages can be of a fixed position layout can be found in table 3.1.

Table 3.1: Table over main advantages and disadvantages of fixed position layout

ADVANTAGES	DISADVANTAGES
Flexible in regards of: - Design changes - Operation sequence - Labour availability	Expensive (if capital investments is for one-off products)
Cost effective (if similar products are being processed but at different stage in progress)	Low utilisation of equipment (due to long duration)
-	Large space requirements

3.6.4 Product layout or Line production

Product layouts are dedicated production lines used for manufacturing one specific product (Zandin, 2001, c.112). Traditionally it is usually adopted for products produced in big volumes, mass production, with small varieties. If there is a need for small varieties in a dedicated line, it needs to be achieved through minimal setup (Zandin, 2001, c.112). However, line production has more recently also gained importance in low volume production with more customised products (Boysen et al., 2008). As illustrated in figure 3.2, the product move through a sequence of stations, containing all resource needed for one operation, and each unit is processed as it passes through (Baudin, 2002). The stations are usually aligned in serial manner (Boysen et al., 2008)
Assembly line systems can be very efficient if designed properly. To properly implement an assembly line system the entire production system needs to be considered and the assembly line system adapted to suit it (Thomopoulos, 2013). Assembly line system varies from production system to production system but there are three main categories that can be described.

Single model line

A single-model line means that an assembly line is dedicated to one single product. There are no variations in the product and no variations in work tasks. The modern single model assembly line is often referred to having its origins from the mass production Henry Ford and his driven assembly line for the Ford model T.

Mixed model line

In mixed-model assembly lines, more than one product can be produced at the same line. The line stations are balanced for all products being run at the line but it also has to be sequenced. The products on the line is run in a sequence that is based on customer demand and it is essential that setup times are kept low in order to maintain a smooth flow. In order to maintaining a smooth flow at a mixed-model lines, production processes should be similar so that the cycle times are not too uneven (Boysen et al., 2008) (Thomopoulos, 2013).

Multi model line

As in mixed-model lines, multi model lines are also used for producing more than one product at the same line. However, the production does dot occur in sequencing since the production process differ too much or the set-up time are too high to be ignored. Production therefor has to be performed in batches and the line requires set-up time between the running of different products, in order to suit the production of the next product. The line is treated as a single-model line but it gives more flexibility (Boysen et al., 2008) (Thomopoulos, 2013). The main advantages and disadvantages can be of a product layout can be found in table 3.2.

Table 3.2: Table over main advantages and disadvantages of product layout

ADVANTAGES	DISADVANTAGES
Reduction in material handling costs	Balancing losses
Better production control	Very rigid and inflexible, if something breaks many processes are affected
Requires less floor space	High investment cost
Reduction in WIP	Expansion is difficult

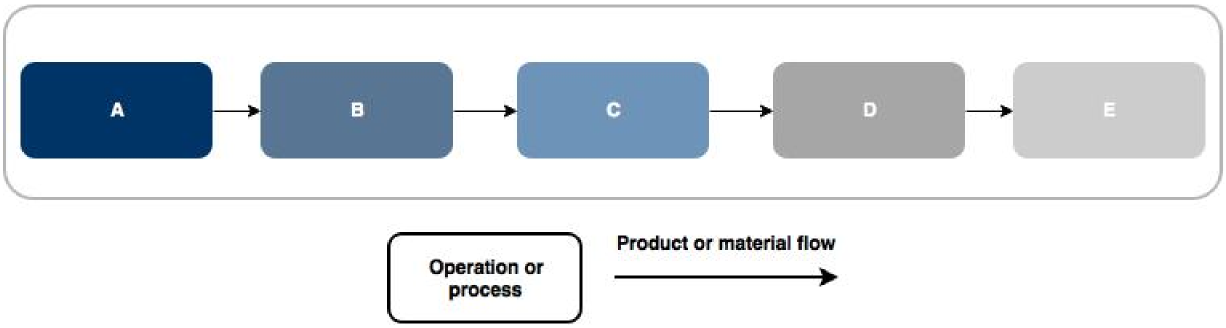


Figure 3.2: Illustration of product layout

3.6.5 Process layout or Functional layout

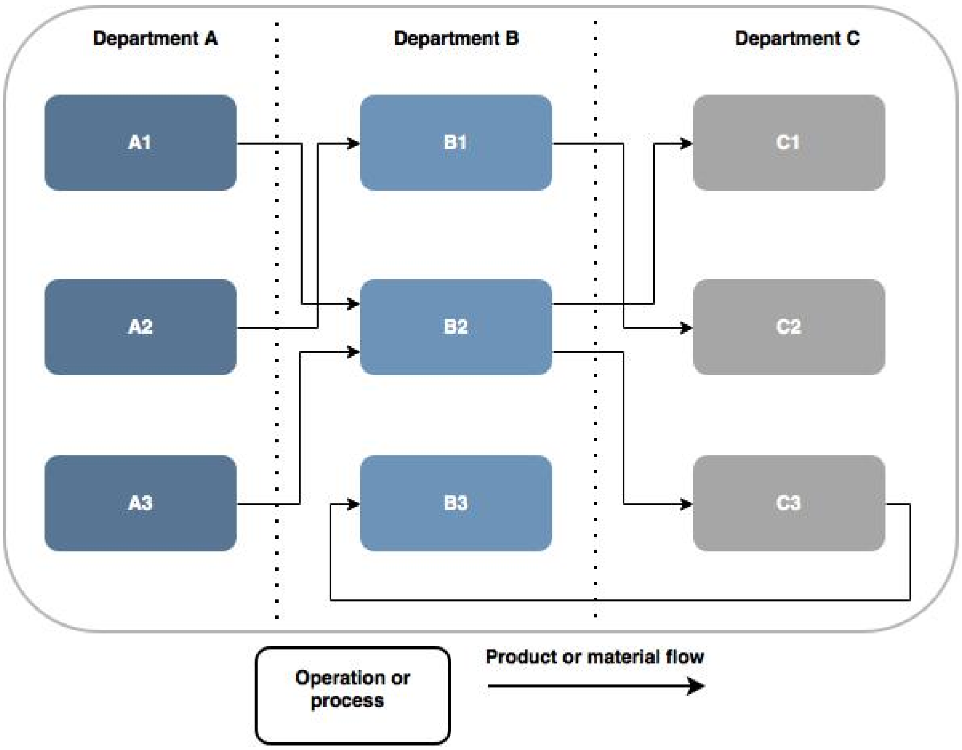
Process layout, also known as functional layout, is characterised by similar machines or operations being located at one place, grouped by their functionality. In this type of layout, the work piece travel from one machine group to the next in a unique sequence, see figure 3.3, and criss-cross movement and backward flow is not unusual (Zandin, 2001, c.112). This type of production is useful when there is a wide diversity in the product flow since each product can take its own routing. Therefore, this type of production is useful for small orders. This is due to the unique requirements of each order and typically the order size also defines the batch sizes (Zandin, 2001, c.112).
Due to the irregular and unique flow patterns through the factory, detailed planning and control is necessary (Zandin, 2001, c.112). Also, set up and work in progress (WIP) tend to be high. Actual machining time constitutes only a small percentage of the actual lead time and the machine utilisation is usually very varied (Zandin, 2001, c.112). The main advantages and disadvantages can be of a process layout

can be found in table 3.3.

Table 3.3: Table over main advantages and disadvantages of process layout

ADVANTAGES	DISADVANTAGES
Very flexible enabling high variety	High WIP due to accumulation
Reduced investments cost since machines are generally specific purpose machines	Machining time low, % of total lead time
More efficient supervision	Fluctuating machine utilisation
Higher utilisation of equipment and operators	Difficulties in material handling, movement of material in appropriate devices
Easier handling if equipment break down by transferring to another machine	More floor space is required
Greater incentive for individual worker to increase his/her performance	Production control difficult

Figure 3.3: Illustration of process layout



3.6.6 Cellular Manufacturing layout

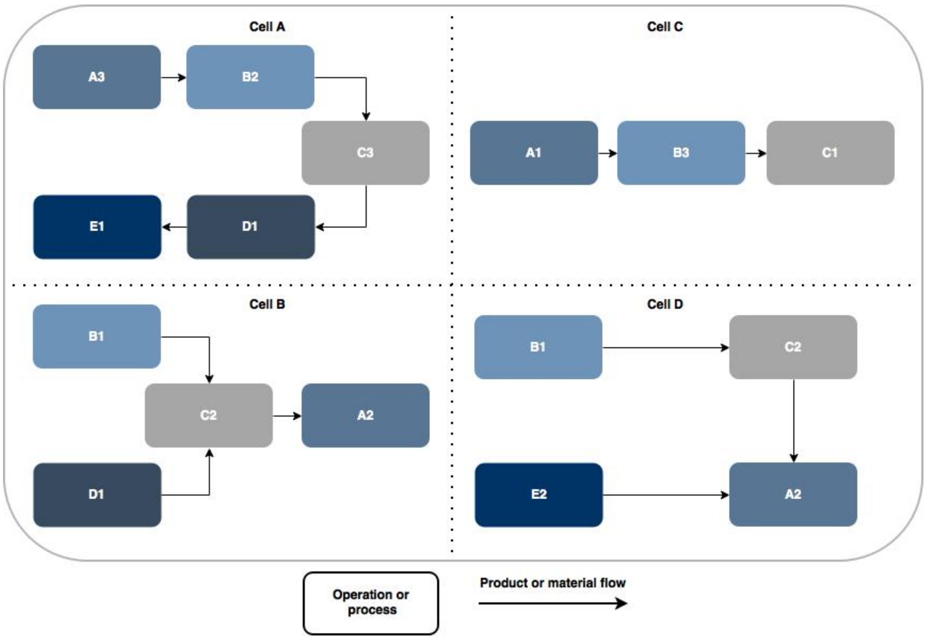
Cellular layout is a combination of both process and product layout. It is suitable when a large variety of products are needed in small volumes or batches (Kachru, 2007). It incorporates each of the above mentioned layouts best and most efficient attributes (Kachru, 2007). By grouping into a product families, it enables parts to be produced more economically than with traditional layouts (Kachru, 2007). When a product family is identified its resources in the form of similar machines, labour skills and tooling are clustered together into a machine cell (Kachru, 2007)(Zandin, 2001, c.112). In these cells, the production flow can be streamlined. Therefore in establishing an effective cellular layout, a crucial step is to form the best product families that tries to eliminated inter-cell transfers(Zandin, 2001, c.112)(Kachru, 2007). In other words, the traditional process layout characterised is changed into a small and well-defined product layout, see figure 3.4. The arrangement of these machine cells is called a Cellular layout.

As mentioned previously, the internal cell layout determines how efficient, economical and practical the cell will be be in the long-term. An efficiently designed cell will have standard operating procedure for different throughput and production rates, with setups and material handling being minimised (Zandin, 2001, c.112). The cell must be flexible in its mix of capacity by being large enough so that the absence of one operator does not force it to shut down(Kachru, 2007). However, it also needs to be low enough for the operators to understand and identifies all the products and operations (Kachru, 2007). As a way to achieve this, it is common to adopt the U-shaped assembly line. The U-shaped assembly line provides the operators with a good overview, increases teamwork and consumes less occupied space and reduce walking distances (Kachru, 2007).

Table 3.4: Table over main advantages and disadvantages of cellular manufacturing layout

ADVANTAGES	DISADVANTAGES
Lower WIP inventory	Reduced manufacturing flexibility compared to process layout
Reduced material handling costs	Increased machine down-time (since machines are dedicated to cells and may not be used all the time)
Reduced distance in material travel	Costly to change if products or processes change
Simplified scheduling of materials and labour compared to process layout	Balance problems such as balance losses
Quicker setup and fewer tooling changes	Different work cells may require same equipment causing duplication resulting in higher investment cost and lower utilisation.
Improved functional and visual control	-

Figure 3.4: Illustration of cellular manufacturing



3.7 Balancing

For a product flow layout to perform efficiently, the assembly line needs to be balanced. All manufacturing and assembly tasks can be decomposed into work elements. A work element is a discrete task required for the processing of a given product (Zandin, 2001, c.130). Also, each work elements has set of work elements that must precede itself (Zandin, 2001, c.130). When balancing an assembly line all work elements needs to be distributed to different work stations while not disregarding any precedence rules.

3.7.1 Product families

Before balancing can be started, it is a good idea to form or evaluate already existing product families.

A product family is a group of products that pass through similar processes or equipment and have similar work content (Duggan, 2012). Product family forming can be accomplished using different methods and principles of grouping technology (Kachru, 2007). One method to use is a production flow analysis (PFA), explained by(Olhager, 2013). PFA ends up in a product family matrix, which can either be used as a simple visual tool or as a complex mathematical tool (Duggan, 2012). Either way, the matrix is a grid that shows the correlation between products and their connected processes by listing the products in rows and processes in columns (Duggan, 2012).

The process flow might not always be continuous. In some cases, products flow from one process to the next and back upstream to the first process again. If this is the case, these processes should be listed again the matrix (Duggan, 2012). Also, if a process could be performed by another process, but it is not the primary choice because of setup or slower speed, the alternative process should be marked. To keep the matrix simple and easy to use, it could be a good idea to place only base model numbers in the matrix, if the derivations are non-process-related items (Duggan, 2012).

When all products have been mapped with its related processes, it can start to be sorted visually. By moving rows and columns in the matrix, rectangles in the diagonal is attempted to be achieved in order to find similarities in resource usage (Olhager, 2013). From the matrix, shared resources can then be identified. The first shared resource is the point where continuous flow ends and pull begins. Products with similar processing steps downstream from the shared resource should be grouped together. Products within a now identified product family do not have to follow the exact same process path, some process steps can be skipped or added. However, as a rule of thumb about 80% of the downstream processing steps between products should be should be the same, in order to create a good product family (Duggan, 2012).

3.7.2 Takt time

Balancing means that the work tasks of a product is moved between work stations until all workstations cycle times are lower then the takt time of the assembly line. They should also be as even as possible. The takt time is the time that must elapse between two finished products in order to meet customer demand. It is therefore a function of both the demand and available time according to equation 3.5 (Baudin, 2002).

$$Takt\ time = \frac{Net\ Available\ Production\ Time}{CustomerDemand} \tag{3.5}$$

Since demand often vary, there is usually a design takt time. The design takt time is the minimum takt-time, or highest capacity, the line is designed to support. The line is though usually required to operate at a higher takt time, due to fluctuations, and the challenge is then to ensure that it runs with proportionally fewer resources (Baudin, 2002). Changing the takt time can be a tedious task, especially in assembly since it involves reassigning task among assembly station and operators (Baudin, 2002).

Not all machines are easy to run according to takt driven production. Machinery that take a load of many products at a time and have long process times, such as ovens or paint booths, can be difficult to manage. These machines must not keep the rest of the plant further away from the ideal or takt driven production than needed. Also, the batch sizes should be different in different parts of the production (Baudin, 2002).

3.7.3 Assembly line balancing problem

In the assembly of a product, many work elements are involved. To properly assign these elements along the assembly line, with respect to some objective, is known as the Assembly Line Balancing Problem (ALBP). Any type of ALBP consists of finding a feasible line balance where tasks are assigned to workstations with precedence constraints and other restrictions such as labour, facility and equipment requirements fulfilled (Boysen et al., 2008). There are therefore many challenges when balancing an assembly line but the core of any ALBP is to make the work package assignments in such a way that operating costs are minimised and productivity maximised (Zandin, 2001, c.130).

It is difficult to measure and predict the costs of operating an assembly line. Therefore, an alternate measurement is the assembly lines efficiency (E) . This is measured as the productive fraction of the lines total operating time according to equation 3.6, where t_{sum} is the total sum of all task times, m is the number of works stations and c is is the cycle time (Boysen et al., 2008).

$$E = \frac{t_{\mathrm{sum}}}{mc} \tag{3.6}$$

Therefore, ALBP should focus on one of the following three objectives on order to increase the efficiency (Zandin, 2001, c.130):

1. To find a combination of cycle time and number of workstations, which results in a minimum sum of idle time.
2. To reduce labour costs by minimising the number of workstations on the assembly line. Here, the production rate is known in advance, resulting in a fixed cycle time. An additional constraint is that the processing times at each workstation, determined by the sum of the task times assigned to the workstation, cannot exceed the cycle time.
3. To minimise cycle time for a given number of workstations by balancing the line.

Balancing decisions have long–term effects and therefore the balancing objective has to be carefully chosen considering the strategic goals of the company (Boysen et al., 2008).

3.8 Lean manufacturing

Lean manufacturing can be viewed as a production philosophy that aims to give an organisational culture of constantly improving every process, while eliminating wasteful activities as much as possible. It consist of key principles and a wide range of tools that supports the principles and the philosophy. In order for an organisation to become Lean, it is necessary to keep a holistic view on organisational processes and use the tools in a way that enables a lean culture. In this section, some of the principles and tools relevant for this project are described.

The term Lean origins from 1990 when the book "The machine that changed the world" was published, written by James P. Womack, Daniel T. Jones and Daniel Roos. The term was coined as the conceptualised form of Toyota Production Systems (TPS). The book describes the philosophy and principles of the successful production system of Toyota and came to change they view on manufacturing within the mass-producing manufacturing community. TPS has evolved into what it is today over many years and it is still evolving. It was Toyotas solution to be able to compete with companies in western countries with their expensive technologies and mass production (Dennis, 2007).

3.8.1 The eight wastes of Lean

The idea with Lean manufacturing is to constantly focus on creating customer value while eliminating waste. Wastes are all activities that do not add value to the customer. According to Lean, there are eight different types of waste.

Overproduction
Overproduction is to manufacture products before there is a real customer demand and it is considered as the worst form of waste since it contributes to all other forms of waste. Overproducing is often the result of basing production planning on forecasts rather the actual customer demand. It makes companies producing too many products, large batches than necessary and too fast or too earlier then the next process in the production flow requires.

Inventory
Having inventory in buffers and storage is often necessary in order to be able to deliver to customers on time. However, having excess inventory binds up capital in materials and products, hides problems and takes up space. Lead times can become vary long which makes it difficult to response well to fluctuations in customer orders.

Waiting
Waiting is when products are not being processed or moved and time is spent on waiting for necessary conditions. Waiting can for example be due to lack of information, lack of material or waiting for people that are late.

Transportation
Transportation means transportation of material between processes, internal and external. Internal transportation is considered pure waste and can be minimise through smarter layouts and logistic planning. The aim is to minimise the need for transports as much as possible, not too come up with smarter solutions to transport material (Petersson et al., 2010).

Motions
Unnecessary motions are considered waste. Walking to fetch tools or material is a

waste and can be minimised through smarter workplace designs. Motions should be made as small and easy as possible to perform, from both a waste and ergonomic perspective .

Over processing
Over processing means performing operations that are not adding value for the customer. Working with unsuitable techniques, oversize equipment and producing products with a higher quality then needed are example of what may add to the waste of over processing.

Defects
Producing defect products is a waste since producing defects requires rework. When minimising this waste, the focus should lie on finding out why the defect occurred and then prevent it.

Unused creativity
This waste is considered an addition to the original seven wastes and it is about not utilising the full competence of employees.

3.8.2 Standardised work

Standardised work is about making everyone work in the same, best known, way and allow for less individual variations and continuously improve the work method. A good standard should describe what, how and in what time work should be done. Having standardisation makes for high quality and efficiency and also provides a safer workplace and good ergonomics. The purpose of standardisation must be communicated thoroughly so that workers understand the need for it and not be sceptical. Involving workers in creating work standards is good for this purpose but also to ensure a good level of detail and content since the workers are the experts of their work (Petersson et al., 2010).

3.8.3 Just in time

Production planning is often based on forecasted demand and not the real customer demand. This type of planning is called a push system, since you push products onto customers. This makes for expensive production with high inventory and over-production is common. Just in time production (JIT) is about producing the right product, at the right time, in the right quality and it is comprised by Takt, Continuous flow and Pull systems (Dennis, 2007).

Takt
Takt is a principle that decides the pulse of the production flow and it is set at a levelled rate that meets the real customer demand. The takt states how much should be produced and at what time. As already stated, the takt time is calculated as the planned production time divided by the customer demand (Petersson et al., 2010).

Continuous flow
Continuous flow is a principle that strives to keep products continuously moving throughout the production system through minimising stopping points and stopping times, since that only adds waste. Aim for short distances between production processes, minimising buffers and package size and minimise transports (Dennis, 2007).

Pull systems
Pull systems is a JIT-principle that strives for controlling the production flow at a point as close to the customer as possible. Kanban is a visual tool that can be used for this purpose since it allows for the transfer of demand between processes. It is used as a form of ordering system that for example can consist of simple cards being transferred between stations to show that a process is in need of material (Dennis, 2007).

3.8.4 5S

5S is the most well-known tool of Lean and it is used to organise and improve workplace productivity. The aim is to encourage workers to constantly reduce waste. It is done through iterating the five steps of the 5S-methodology (Dennis, 2007).

1. **Sort**
   Sort among the workplace items and remove unnecessary items of that are non-value adding.

2. **Straighten**
   Set the workplace items in order in a way that makes them easy to find, use and put away.

3. **Shine**
   Shine is about cleaning the workplace and the workplace items. It makes the workplace more visual and helps workers detect malfunctions of equipment.

4. **Standardise**
   Standardise the best practice of the previous three steps and sets a structure that ensure that the standard is being followed.

5. **Sustain**
   Sustain the 5S procedures and continuously maintain the standard decided in order to improve.

3.8.5 Flow efficiency

In order to succeed with Lean, keeping a holistic view of both production resources and flow is essential. As (Modig and Åhlström, 2012) states, most organisations are far too focused on resource efficiency and the flow efficiency is often disregarded from. In an attempt to clarify the goal of Lean and the importance of both resource and flow efficiency, (Modig and Åhlström, 2012) has developed a framework called the Efficiency matrix. The efficiency matrix can be seen in figure 3.5 and it describes the different states an organisation can be in depending on how focus is put on resources and flow efficiency.

Efficient islands

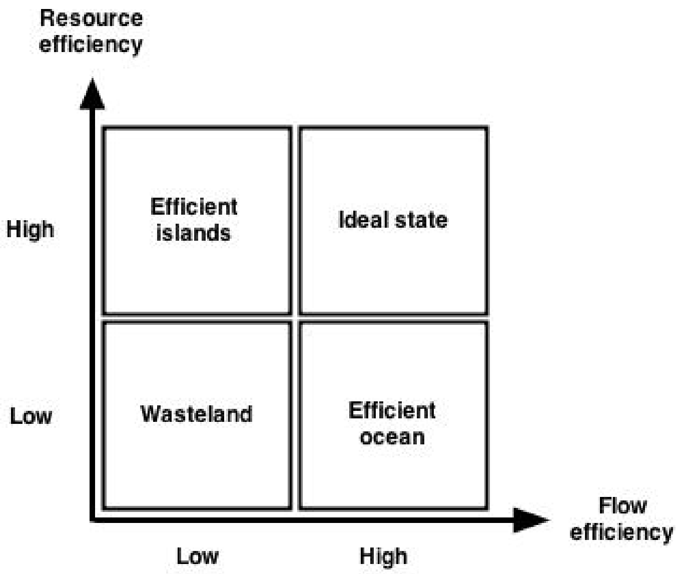


Figure 3.5: Efficiency matrix

Efficient islands is the state that organisations end up in when they have a high resource efficiency but a low flow efficiency. The processes within an organisation are separated from each other and are focused on individual performance, with maximising utilisation of resources within each process. Focusing on resource efficiency will reduce cost of produced goods but it also causes a lot of waste in form of waiting and high inventories, which makes for a low flow efficiency and possibly a cause for hidden costs.

Efficient oceans
Efficient oceans is the state that is reached when an organisation has a high flow efficiency but a low resource efficiency. In this state, the processes within an organisation is not considered as individuals but as a system of processes that strives for efficient flows in order to please customers. The state has a high customer focus and resources are not used efficiently but are utilised only when there is a customer need. Resource overcapacity is used in systems like theses in order to always be able to please the customer.

Wasteland
Wasteland is the state where both resource and flow efficiency are low. Resources are not used in way that saves cost and the flow is not creating any specific customer value.

Ideal state
The ideal state is reached when both resource and flow efficiency is high. This state is a difficult state to reach. The difficulty lies in that every system has its variations that can not be removed but must be considered while simultaneously focusing on both resource and flow efficiency.

According to (Modig and Åhlström, 2012), *Lean* is the answer for organisation that wish to reach the ideal state and to avoid the trap of too much focus on resource efficiency. The efficiency paradox, described by (Modig and Åhlström, 2012), explains how too much focus on resource efficiency actually generates more costs. These extra costs are found in the form of excess work and is due to the lack of flow efficiency.

3.9 AviX

Avix is a set of software from Solme AB that are used for industrial applications. AviX®Method is software that can be used with several modules, such as resource balancing. The software also has modules that for example supports Failure Mode and Effects Analysis (AviX®FMEA), Design for manufacturability (AviX®DFX) and ergonomic analysis of the workplace (AviX®Ergo).

3.9.1 AviX®Method

AviX®Method is a software that can be used to analyse manual work in manufacturing. It enables the user to build and analyse work tasks through video analysis, PTS and work-classifications to mention a few of the functions within the software. It is easy to store information about manufacturing processes in the software and also very easy to interpret it. AviX®Method makes it possible to work efficiently with increasing productivity, work with continuous improvements and creating optimal conditions for production systems (Solme AB, 2015a)

3.9.2 AviX®Resource balance

AviX®Resource balance is a balancing module within the software. The stored data in AviX®Method can be used and analysed to be able to balance production with operator and machine resources (Solme AB, 2015b). The module is able to visualise balancing losses, man-machine operations and overall efficiencies of production lines. It is also possible to work with balancing multiple variants of a product and aiding in creating improved layouts.

4

Current state

In this chapter, products covered in the specified product mix, from here on denoted SPM, will be presented. Also, an overview of Aros current production systems and capacities of process equipment will be given.

4.1 Product and area related data

In this section, general data over the SPM, the area used by Green unit and products flow will be presented.

4.1.1 Specified Product Mix, SPM

The project aim was to analyse the products within the Green production unit that requires the wave soldering machine. Hence, the process flows of these products in the unit were mapped and summarised. Many of the products are produced in variants but with some differences. The differences can be software or hardware, which may or may not affect the process flow and the work tasks required by the operators. Originally, the plan was to cover all of these mapped products. However, product changes were made during the project which affected the processes flows of some products. Some products were planned to be phased out entirely and some product are planned to move to the Yellow unit. The final SPM of the project can be seen in table 4.1. It was assumed that the current way of producing the SPM was close to max capacity. The production volumes sometimes differ but a representative production volume, close to max capacity, are given in table 4.2. These volumes are based on Week 19, year 2015, and the volumes were given from an internal-document referred to as "Takt-data". Takt-data is a living document where the production planning department tries to level out the demand, based on both actual orders and forecast, to achieve an even takt of the production. The takt is set in a 4 weeks period and for the SPM, Week 19 was judged to be representative for normal production volumes. An exception to this were the articles 1399-6* and 1379-6*. Together with the production manager, a more representative weekly volume was decided for these products. To conclude, the weekly product capacity, based on Week 19, was summarised to 877 products.

4.1.2 Area utilisation

Since one of the projects aims were to reduce the area occupied by Green unit, the current occupied space was to be measured to form as a reference. The floor plan

No.	Product	Variant 1	Variant 2	Variant 3	Variant 4
1	1360	1360-502			
2	1068	1068-603	1068-503		
3	1314	1314-603			
4	1364	1364-501			
5	1290	1290-601			
6	1289	1289-501			
7	1240	1240-501			
8	1172	1172-503			
9	1097	1097-517			
10	1197	1197-501			
11	1096	1096-514			
12	1344	1344-501			
13	1226	1226-501			
14	1379	1379-601	1399-602	1399-603	
15	1399	1399-605	1399-606	1399-607	1399-608

Figure 4.1: Product included in the final SPM

No.	Product	Variant	Volume
1	1360	1360-502	177
2	1068	1068-603	59
		1068-503	60
3	1314	1314-603	25
4	1364	1364-501	20
5	1290	1290-601	20
6	1289	1289-501	20
7	1240	1240-501	10
8	1172	1172-503	16
9	1097	1097-517	30
10	1197	1197-501	100
11	1096	1096-514	30
12	1344	1344-501	70
13	1226	1226-501	220
14	1379	1379-601	6
		1379-602	-
		1379-603	-
15	1399	1399-605	18
		1399-606	-
		1399-607	6
		1399-608	-
Total product volume [W. 19]			887

Figure 4.2: Production volume for products included in the SPM

of Aros entire production floor was obtained from the property and environmental department of the company. The floor space occupied by each production unit was then mapped in the floor plan. This was done by simplifying each production units occupied floor space to simple geometric forms that were then added to the floor plan. To separate which areas were used by which unit, the rectangles were colour coded. From this mapping, the current floor space occupied by the SPM in Green Unit could be estimated by rough calculations. The current state occupied approximately 170 m^2. This area then excludes the wave soldering machine area, the coating room and work areas occupied by Orange production unit, Blue production unit, service departments and other products not belonging to the scope. In figure 4.3 the current production layout and work areas of the different production units can be seen.

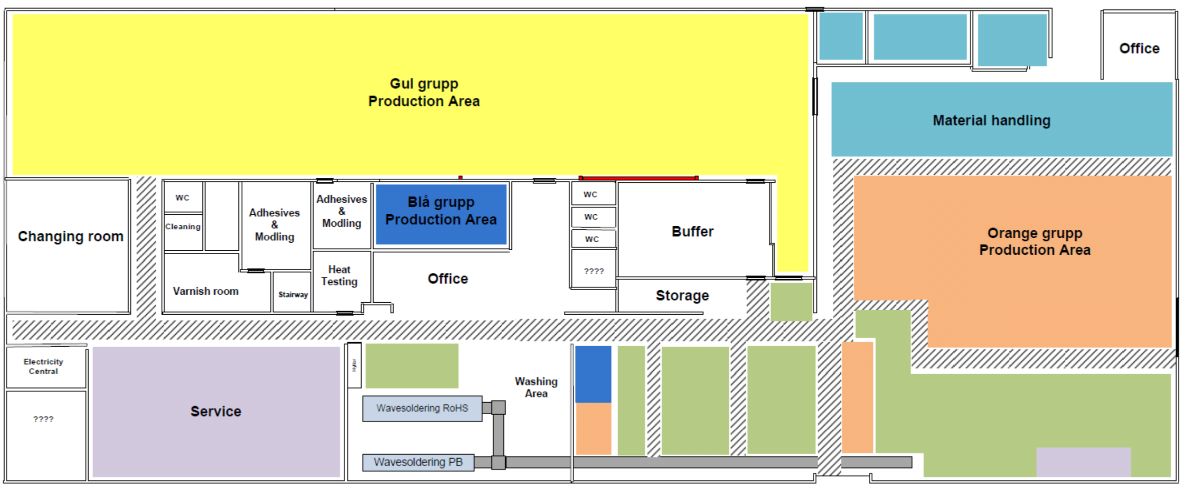


Figure 4.3: Current production layout

4.1.3 Process flows

The process flows of each product in SPM were mapped. In order to know which processes where needed for each product, work instructions for each product were downloaded from Aros intranet. From this, a first draft of a list over each products required processing steps and precedence was made. This list was then confirmed with the operators to ensure that the right processing steps and its precedence had been correctly interpreted. Each list was then finalised. From the precedence lists of the processing steps, a product/process map was made to summarise the flows. The first version of the product/process map contained all processing steps in a sequential order in an attempt to easily visualise required processes for each product. If two products contained the same processing step but made in different orders, the process step was added again as a different processing step in the map. This made the the product/process map very long and difficult to overview, so a new version was made. The second map only contained each unique processing step once. The product routing was then visualised through sequential numbering within each cell, see figure 4.4. This made the product/process map much easier to overview.

To make the current SPM flows more visual, all process equipment, tables, racks, pallets, shelves and aisles where mapped and each products current flow could drawn in the floor plan. An overview of these flows can be seen in figure 4.5.

Process / Product	THM	AOI	Wavesoldering	Test: ICT	THM & Manual Soldering	Assembly	Test: Functional	Test: WK 1	Test: WK 2	Varnish	Adhesive	Audit	Test: Multimeter	Test: Isolation	Test: Tightness	Test: High-voltage	Packaging
1360-502	1	2	3	4		6, 9	5, 8									7	10
1068-503	1	2	3	4		6, 9	5, 8									7	10
1068-603	1	2	3	4		6, 9	5, 8									7	10
1172-503	1		2			3,7,9	4,8			5	6						10
1097-517	1		2	4		6,9	5,1			7	8		3				11
1096-514					1	5	2			3	4						
1197-501	1		2	3		4	5										6
1344-501	1		2			3	4										5
1314-603	1		2	3	4	7,9	5,12				6	8		10	11		13
1289-501	1		2		3			4									
1290-601	1		2			4,6	5	3									7
1364-601	1		2		3	6,8	5,7	4									9
1226-501	1		2			3			5		4						9
1240-501					1		2,5			4	3						6
1379-6*						1,3	2										4
1399-6*						1,3	2										4

Figure 4.4: Product/process map illustrating each products sequential processing steps for the SPM

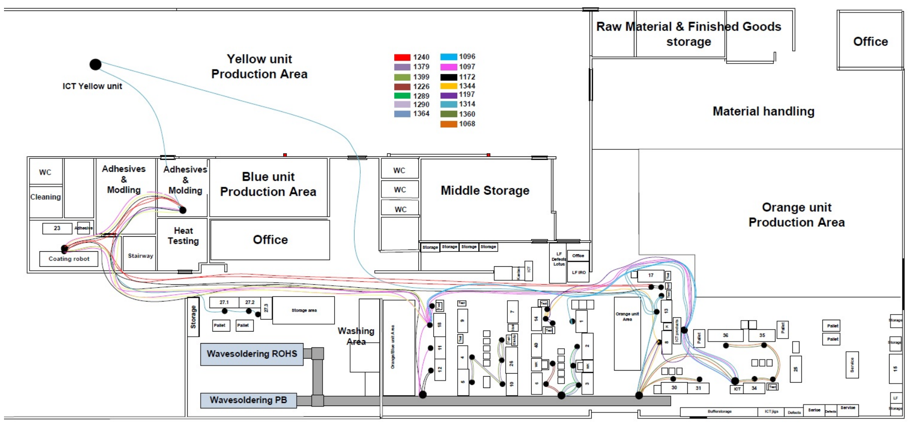


Figure 4.5: Overview of product flows for products included in the SPM

4.1.4 Volume data

In order to get and understanding of product fluctuations, yearly volume data for the SPM was collected. The data was gathered through Aros purchase department and shows the history between years 2011-2014. The fluctuations can be seen in figure 4.6. Their help was required since the authors lacked access to Axapta, Aros Enterprise Resource Planning system (ERP) where the data could be collected from.

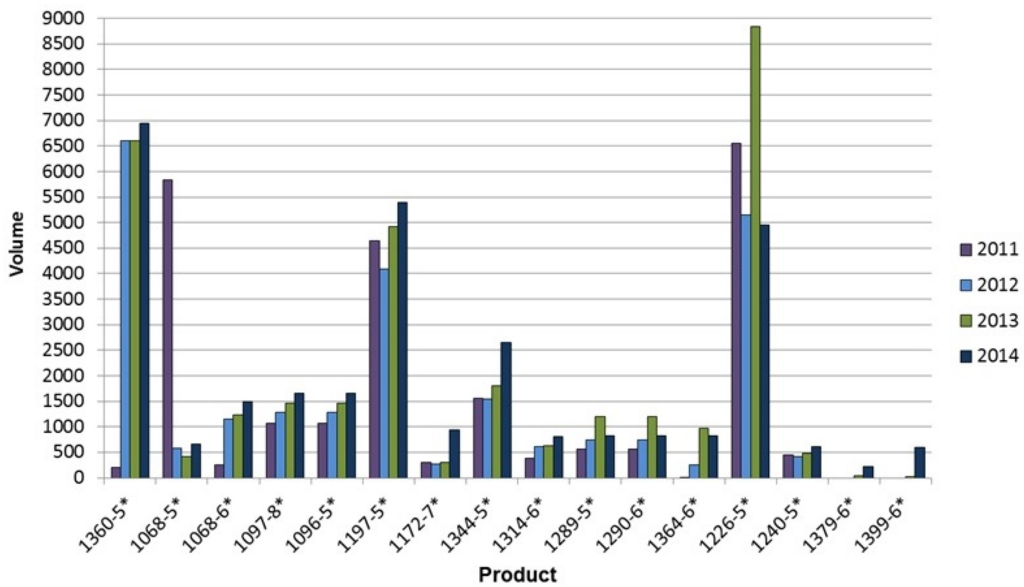


Figure 4.6: Product volumes 2011-2014

4.2 Testings equipment data

All products need to go through multiple tests before being finished. The type of testing a product requires vary but all products at least need to pass a In-Circuit-Test (ICT) at some point. It though varies when, in the products processing steps sequence, that the ICT occurs. Since the ICT is a shared resource, the ICT is in the analysis distinguished from the other test, that are more product sepcific. All product specific test are in the analysis grouped under the name "Functional test".

4.2.1 ICT

The ICT Equipment, see figure 4.7, can be used for most products, as long as there is a jig program for that specific product. All products need to go through an ICT and Aros in total has three of them. One is placed in the Green unit department and two are placed in the Yellow unit department. Not all products in the SPM are tested in the ICT placed in the Green unit. This since they have already been tested in in the Yellow unit. The ICT in Green unit is used to test six of the products from the SPM, three products from the Orange unit and a varying amount from Blue unit. The ICT is currently run in two shifts a day, where the day shift is dedicated Green units high runners: 1360-502, 1068-603 and 1068-503. The other products requiring ICT, are placed in an buffer to the night shift. On the night shift, one operator tests all the products from the buffer so they can continue to their next processing step on the following day.

Figure 4.7: ICT equipment located in Green production unit

Figure 4.8: Common type of functional test in Green production unit

4.2.2 Functional tests

One of the limitations in the thesis was to improve the production flow using existing equipment. The amount of testing equipment at Aros is extensive and most of their test are quite old and inflexible. This is because has a lot of long-runners in their product range which still has their original test equipment in use. The test equipment in Green unit has a wide range of test types. The process map felt insufficient in providing all required data needed for the current state analysis and therefore, a full summary of test equipment belonging to product scope was made and can be seen in table A.5, appendix A. Test id-numbers were mainly collected from work instructions. Some work instructions did not include this information so these id-numbers where instead found on labels marked on the physical test equipment. Some test equipment was not marked at all and these id-numbers were then received from the flow-technicians.

A test usually consist of three components: a test unit, a computer and a test fixture or test jig. An example of a common test type in the production is the test that can be seen in figure 4.8. The lower part is the part referred to as a test unit and the upper part is referred to as jig or fixture. The test unit itself is a type of universal test. It can used for other test but as for the ICT equipment, other jigs and other programs are then needed. It differs greatly between the functional tests on how product specific they are. Some are dedicated to only pre-testing and can test a few different products changing the testing program or jig. Other test can be used for both pre-tests and final functional-test and are then usually dedicated to only one product type.

4.2.3 Testing equipment yields

Data from most testing equipment is logged and collected in a database called T-log. For this project, the stability of each test was required in order to provide a representative an obtainable production flow. Two values was considered to be interesting from T-log: First pass yield (FPY) and Test equipment yield (TEY). FPY and TEY where collected for all tests registered in T-log. The yield data was collected for test registered in the time period 1/10-2104 - 30/4-2015 and summarised in table A.6, see appendix A.

FPY is calculated according to equation 4.1 and shows in percentage of how many products that get a pass in the designated test in the searched time period. It is an attempt to show the quality of the product but its validity suffers if there are many so called false-stops. A false-stop is when the product does not have a a quality issue that requires service to fix it, but the operator themselves can solve it.

$$FPY = \frac{(NumberOfUniqueTests - NumberOfFirstPassFailedTests)}{NumberOfUniqueTests} \tag{4.1}$$

TEY is calculated according to equation 4.2 and shows in percentage of often a product passes a test regardless of if it is the first time or not. It is an attempt to show the quality of the test equipment but its validity suffers if it is a product with many quality issues.

$$TEY = \frac{(NumberOfTests - NumberOfFailedTests)}{NumberOfTests} \tag{4.2}$$

4.2.4 Test equipment process times

Process times were collected for each test in two ways: Manual measurements using a stop-watch or by calculations of logged start and end times collected from T-log.

Measured process time
Measured times were taken between February through April. An average of five different tests were aimed to be measured but when test was very long or stable fewer runs where collected. A process time was judged to start when the product was scanned, and finished when the screen connected to test showed a pass.

Logged process time
Every tests process time is logged in T-log regardless of the outcome of the test. For all tests 3-5 randomly picked serial numbers between the time period 1/10-2104 - 30/4-2015 were checked to receive their process time.

4.3 Wave soldering process

There are two wave soldering machines, one for leaded products and one for lead free products. The lead soldering machine, see figure 4.9, is referred to as the PB-machine and the lead free, see figure 4.10, as ROHS-machine. ROHS is short for Restriction Of certain Hazardous Substances, which is a EU directive that aims to minimise the amount of the following six hazardous substances: (EUR-Lex, 2011).

- Lead
- Mercury
- Cadmium
- Hexavalent Chromium
- Polybrominated Biphenyls
- Polybrominated Diphenyl Ethers

Figure 4.9: PB-machine

Figure 4.10: ROHS-machine

4.3.1 System description overview

The wave soldering process, seen in figure 4.11, consist of the two wave soldering machines (PB and ROHS) and a conveyor transportation system, see figure 4.12. Products are transported in mixed sequence to and from the machines in a frame. Below follows a step by step description of the whole wave soldering process.

- **Station Loading/Unloading:**
  The loading of products starts at station 1-4 and products travel from there, via a constantly moving conveyor, to a Split & Merge point (A) just before the soldering machines.

Figure 4.11: Wave soldering area

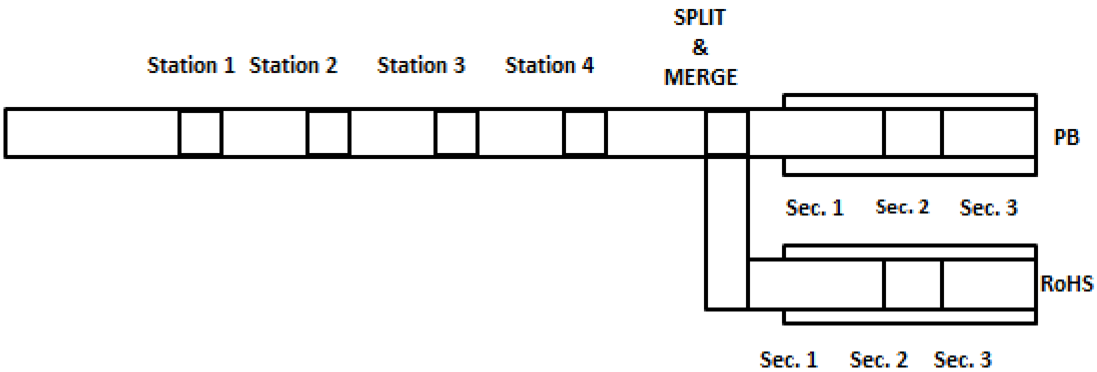


Figure 4.12: Illustration of the wave soldering process including the conveyor system and two soldering machines

- **Split & Merge point:**
  A bar code on the frames is scanned and checks whether the product should go to the PB-machine or the ROHS-machine. It then gets sent to the intended soldering machine and stops when it reaches the start of the process.

- **Start of process:**
  The frame is stopped thorugh a triggered sensor and after a while, the product is moved inside the machine.

- **Process time:**
  The product is first covered in flux material, required for the soldering. It then travels via a heat tunnel to the wave soldering point and is soldered. After this, the product moves on to the end of the machine to then go back out on the lower level of the conveyor system.

- **Transport back to stations:**
  The product moves from the end of the machine, back to the Split & Merge-point and then ends up back on the station that it came from. The lower level conveyor has a higher speed then upper one level.

4.4 Coating Robot

Each operator working with a product that requires coating need to use the coating robot, see figure 4.13. It is a shared process equipment between Blue and Green production unit. The operator that need to use the coating robot has to book up a time slot for when they intend to use it. The booking is made manually by signing a paper schedule placed on the wall in the coating-room.

Figure 4.13: The Coating robot

4.4.1 Processing times

When the process is to be started, the operator makes a set up on the robot, selects the right program and insert the product/products. The process time for the machine varies between products but the range is between 47-430 seconds. After the coating has been applied, the products needs to dry before it can continue to the next processing step. Drying times vary from 1-12 hours and therefore this activity is very time consuming, especially when both sides of the product require coating. For full list of each products required coating process times and drying times, see table A.4, appendix A.

4.4.2 Coating robot capacity

The full capacity of the coating robot has not been analysed in this project. The reason being that according to production managers and production leader, it is not highly utilised. It should and does not pose a problem if scheduling system and the production plans for the coating products are followed.

4.5 Measuring Process equipment capacities

Most process equipment of the SPM are product specific but there are three process equipment that are shared. The shared equipment are the wave soldering machines, the coating robot and the ICT. Prior to this project, Aros did not have any documented data over the capacities of these equipment. As stated in previous section, the coating robots capacity was not explored since it was not considered a constraint to the system. Efforts where instead aimed towards the the considered bottlenecks.

4.5.1 Wave soldering process capacity

The wave soldering machines are shared between Green, Orange and Blue unit. Therefore its full capacity, once known, cannot be dedicated fully to the usage for the SPM. Also, according to the production manager, it will never be possible to utilise their full capacity and he stated that a realistic number achievable is 80% off full capacity. He also estimated that 20% of the capacity needs to be available for the other units utilising the wave soldering machines. These assumptions was judged to be reasonable and no further analysis of them were made. Based on these assumptions, it was calculated according to equation 4.3 that the final balance suggestion cannot utilise more than 64% of the of the wave soldering machines full capacity.

$$\text{Dedicated Capacity for SPM in Green unit} = 100 \times 0,8 \times 0,8 = 0,64 = 64\% \quad (4.3)$$

Wave soldering process
There were no obtainable data over the capacity of the wave soldering machines so it had to be measured and calculated. It was decided that the wave soldering process started when the soldering-frame was loaded to the conveyor and finished once the frame reached the electrical elevators at the work station.

Two scenarios was identified as possible constraints to the process. The capacity could either be constrained by the speed that split & merge reads and moves through frames to the different soldering machines. Or it could be the soldering machines themselves and how often it is possible to send in a new frame. Both scenarios were exploited as well collecting time data for the conveyor.

Capacity of Split & Merge point
The split & merge point is the first point in the wave soldering process that could pose as a constrain. Depending on which type of soldering frame that arrives, the split & merge has a different rotating pattern. If the frame is going to the PB-machine it is sent straight ahead with no need for the rotating conveyor section to shift. If it goes to ROHS-machine, it has to rotate 90 degrees when the frame has moved onto it and once the frame has left the section also rotate back before another frame can start. If the split & merge is the constraint, it should be the maximum time from frame one starting to move from the starting sensor until frame two starts moving from the starting sensor. Since the frames arrive in a mixed sequence, depending on when operators load a frame, four combinations were to be analysed.

1. Same type of frame PB-PB

2. Same type of frame ROHS-ROHS
3. Different type: ROHS first, PB last
4. Different type: PB first, ROHS last

Time data for each combination can be seen in table A.1, appendix A.

Capcity of ROHS-machine and PB-machine
If the machines were the constraints, it was relevant to find out the time on how often a new frame can be sent into each machines. Both machines were exploited in the same manner. The estimation started with placing two empty frames, directly after each other, after the split and merge point. The measurements started when frame one reached the start-sensor just before the soldiering machine. Below times were measured, in order to find out how often the soldering machines can process a product.

1. Time from when frame 1 stopped until frame 1 started.
2. Time from when frame 1 started until frame 2 stopped.
3. Time from when frame 2 stopped until frame 2 started.

Time data for each combination and machine can be seen in table A.2, appendix A.

Conveyor
The conveyor was not considered to be a constraint in the system, but the transport time will add to each products current lead time and was therefore needed. The following 12 measurements were taken:

1. Station 1 - Split/Merge
2. Station 2 - Split/Merge
3. Station 3 - Split/Merge
4. Station 4 - Split/Merge
5. Split/Merge - ROHS start
6. ROHS, delay before entering
7. PB, delay before entering
8. Split/Merge - PB start
9. ROHS end - Station 1
10. ROHS end - Station 2
11. ROHS end - Station 3
12. ROHS end - Station 4

13. PB end - Station 1
14. PB end - Station 2
15. PB end - Station 3
16. PB end - Station 4

Time data for each combination can be seen in table A.3, appendix A.

4.5.2 ICT capacity

The capacity of the ICT equipment in Green unit was estimated through the following method:

1. Product volume data was extracted from the takt-data documents of Week 19, for the nine products that use the ICT, six products from Green unit and three products from Orange unit.
2. Test process times were estimated from T-log for these products. Same method was used as can be found described in 4.2.4.
3. ICT FPY for each product was extracted from T-log.
4. A estimation from previous data in the project was used to estimate the manual handling time needed to load/unload products in the ICT.
5. A stopwatch estimation was made to collect the time required for set up. A set up includes changing ICT jig and selecting the ICT program.
6. Finally, a calculation of total time required to test all products needing ICT-test week 19 was made. An assumption in this calculation was that all products were tested as batch according to the weekly volume, hence only nine set ups.

Time data for ICT capacity can be seen in table A.7, appendix A.

5

Analysis

In this chapter, the results from step three and four in the Methods engineering methodology will be presented. For this step, the selected work system to be improved should be analysed and modelled. In this project, this is done by first analysing the Current state through a cause and effect analysis, to identify root causes to problems and constraints within the production of Green unit. After this, the work procedure used in Avix, in order to create work standards, will be clarified and created lead times illustrated. Lastly, the methodology and results from the two live tests will be presented.

5.1 Current state analysis

It was quite clear from the beginning what the main problem areas in the production were but in order to clarify them and be able to find more causes to the problems, a cause and effect analysis analysis was made.

5.1.1 Cause and effect analysis

As can be seen in figure 5.1, there are many factors that influence the capacity problem in Green unit. Below follows a clarification of some of the main problems existing within the Green unit, based on figure 5.1.

Machine
There are a few problems with the process equipment, which Aros are highly aware of. The testing equipment is old, unstable and not maintained properly which causes great instabilities in the production.

An overall problem is that there is a lot of testing equipment with low utilisation. The reason for this is that the tests are inflexible and can mostly only test one specific product. There is however the ICT equipment, that has a low utilisation even though it has a relatively high flexibility compared to the other tests. The ICT first did seem to have a high utilisation, since it requires one operator on an extra shift each day to handle the ICT, but the extra shift is actually only needed due to the instability of the ICT. The extra shift is needed to cover possible stops and not disturb the flow of the high runners 1068 and 1360, that uses it during the day shift.

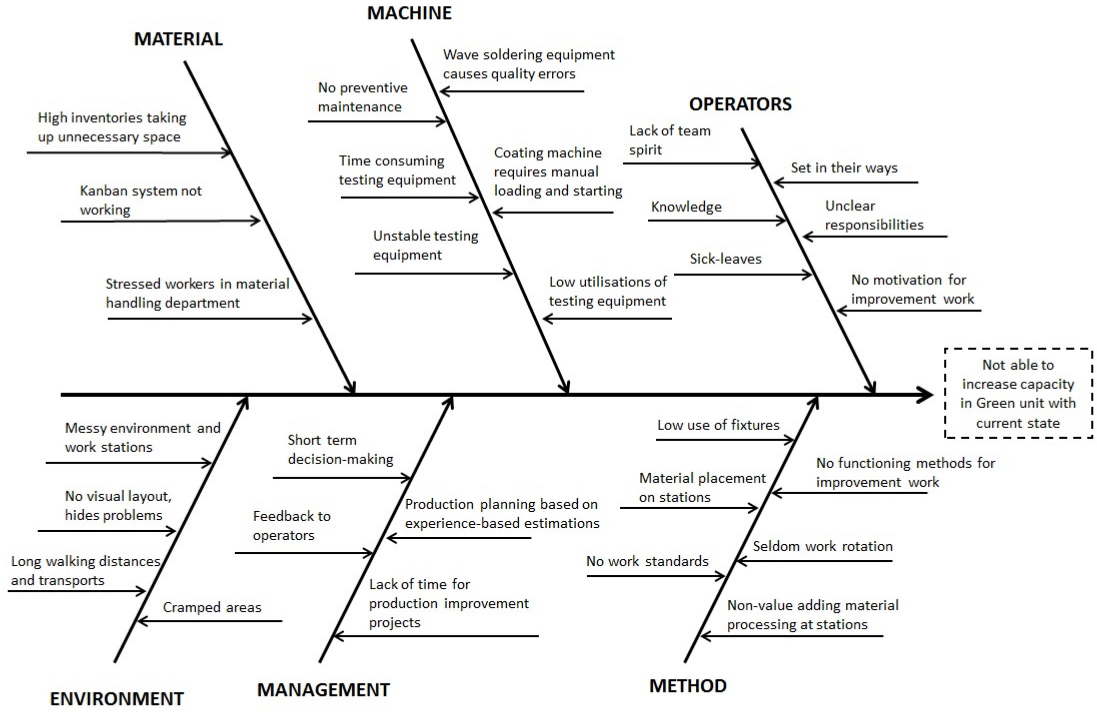


Figure 5.1: Cause and effect diagram

The wave soldering equipment is a process that quite often makes for unclean products when processing, due to flux material, and this requires the operator to clean them before they are run in a test. Otherwise, they will not pass. Also, the wave soldering process currently involves a lot of conveyor transports and it seemed to pose as and unnecessary capacity constraint for the wave soldering machines.

In order to increase up-time and stability of the process equipment, preventive maintenance could be a solution. Clear procedures of troubleshooting with defect products and faulty testing equipment should be taught to the operators in order to save time and increase the quality yield of the production. Reducing conveyor transports and possibly removing the Split & Merge function of the conveyor system is a way of saving lead time but since it also works as a sort of buffer, it could cause storage problems.

Environment

The work environment is overall quite messy with a lot of inventory and materials placed in an already quite cramped space. The layout is attempted to be flow-oriented for each product but it is a difficult task to manage all the product-specific flows, while still managing a visual workplace with as little production wastes as possible. It is also a quite stressful environment from time to time, when process equipment, mostly tests, fails and meeting customer demand becomes difficult.

The 5S system that is currently in use has ended up as a sort of cleaning tool that is used on a weekly basis. It does not encourage continuous improvement work as it should. If Aros 5S worked properly, the environment could be more visual, clean and motivating for the workers. Both the physical and social environment would be improved and hence also the productivity.

Material
As mentioned, there is a lot of inventory and material in production, in larger quantities than it needs to be. The Kanban system that has been implemented does not work properly since there is often too much material at stations and sometimes not enough. The Kanban levels of the the material handling has not been set and/or revised properly. Also, the workers of material handling department are stressed since they often have to adapt and prioritise different products and materials due instabilities in production.

Setting correct Kanban levels would reduce stress for the worker in material handling and reduce the inventory in production.

Operators
A problem with having complete assembly is that it enables a lack of team spirit. It seems as the operators feel responsibility over their own products but not other products within the unit. Many of the operators appreciate this way of working, with high own responsibility, ability to plan their days and not change the product they work with very often. However, some operators enjoy working as a team, as in the Albany production cell where products 1068 and 1360 are processed. They enjoy getting clear directives and do work rotations.

Another problem with the workforce is that it is quite difficult to fill up for operators on sick-leave. Since work rotations are not made very often and there are no work standards, the operators become experts on the products they work most with and therefore the current way of working is quite inflexible and makes the speed of production highly varying.

The inflexibility with the work force could be resolved partly with work standards, since it is easier to have one way of doing things and then teach each operator to work accordingly. It does not entirely solve the problem with inflexibility but to fully do that, work rotation is needed so that as many operators as possible know as many work tasks as possible.

Methods
There are a lot of improvement potential within the Methods area. There are no work standards used in production except for work task instructions and for some products, a few estimated cycle times.
Tools and fixtures could be more adapted to the work tasks being carried out and the placement of materials on stations could be improved to make for faster assemblies. The use of work standards would have a high impact on productivity since the present state allows for high variations depending on which operator performs what task.

Management
As common in production systems, a lot of problems are related to management. In this case, the main problem is that there is a lack of production strategy within the Green and Orange unit. The idea with the Green unit is that it should produce all products using the wave soldering equipment. Green unit does however make products that don't require wave soldering but they also make products that only require manual soldering and/or assembly. The Orange unit mostly carry out final box built assemblies and tests but they also have many products that use the wave soldering machines. There is no clear distinction between the two units other than what customers they are responsible to produce against. With a more clear and distinguished categorisation of products, for example through analysing similarities in process flows and shared resources, the production would be easier to manage and continuously improve.

Time is probably the biggest problem. Management has not enough time for improvement work or feedback to operators but are instead busy with making sure the customer receives their products on time. A problem is that there is no sufficient time data to plan or base decisions on. Planning is based on estimations, historic data and own knowledge which makes Parkinson's law, which states that work will expand to fill the available time (Parkinson, 1957), highly present in the production.

Production management and planning can be improved through relevant and reliable time and capacity data of the resources within the Green unit.
Decided on approach
Since the goal of the study was to balance the production and increase the capacity, it had already been decided that it was necessary to establish work standards and relevant time data for all resources in production. The capacities of the process equipment needed to be analysed along with the manual labour.

As can be seen from the cause and effect analysis, there are quite a few areas that are in need of improvement. Using work measurement may aid a lot in resolving these problem areas since they can provide as a frame of reference for improvement work.

5.2 Analysis of process equipment capacities

In this section, the results of the measured capacities of the process equipment capacities is analysed.

5.2.1 Capacity of wave soldering process

In the beginning of the project, it seemed as the split and merge point of the conveyor system could pose as a constraint if the wave soldering machines were used at max capacity. However, it turned out that this was not the case. As can bee seen below, the constraint at present are the wave soldering machines themselves.

- The PB-machine has a maximum capacity, measured in minimum cycle time, of 38.3 seconds per wave soldering frame. The cycle time was estimated from the process time and how often a product was allowed to move into the machine, see table A.2 and A.3 in appendix A.

- The ROHS-machine has a maximum capacity, measured in minimum cycle time, of 70 seconds per wave soldering frame. The cycle time was estimated from the process time and how often a product was allowed to move into the machine, see table A.2 and A.3 in appendix A.

- The Split/Merge-point has a maximum capacity, measured in minimum cycle time, of 36.9 seconds per wave soldering frame. For this data, see A.1 in appendix A.

Conveyor transports
There are a lot of unnecessary conveyor transports in the production, especially the transport to the station the furthest away from the machines. It is by this station that the production cell for the high runners of Green Unit, 1360 and 1068, are placed. The total conveyor transport time for products going from station one to the Split & Merge-point is 256 seconds and going back is 187 seconds back. The conveyors on the transports back to station has a higher speed than those.

5.2.2 Capacity ICT

Since the ICT in Green Unit is running for two shifts, its capacity was analysed. The process times themselves are not a problem, ranging between 30-47 seconds, but the problem with the ICT is its instability. The test yield for the ICT is low, spanning between 30-95 %, for the SPM. Also, the ICT requires a set up between different products. This set up takes approximately 180 seconds, according to an operator working the night shift.

After an estimation on the ICT capacity, it should in theory be possible to test all products requiring it using day shifts only. The total time needed, including set up, was estimated to be 31.19 hours. The available production time for one week is 38.75 hours. For complete estimation, see table A.7 in appendix A.

5.3 Work Measurements

Below follows the work procedure in creating work standards for both manual work and process equipment. Firstly, the procedure of how precedence constraints and best current practice was decided will be explained. Then follows the assumptions regarding how process equipment cycles times were estimated and finally, how this was implemented in Avix.

5.3.1 Deciding on work standards

Before any assembly sequence could be standardised and an ideal standard time developed, current best practice had to be decided. Since the authors had no prior knowledge of the electronic manufacturing much explicit knowledge from the operators needed to be extracted in order to construct the best currently known work standards.

Precedence list
A processing step is built up by work tasks. Once the processing steps sequential order was known for each product, the precedence of each processing steps different work tasks needed to be mapped. Therefore, each products work instructions was reviewed again in more detail. This time, every new work task was written down in sequential order into a first draft of a step by step work precedence lists. If a work task required a component, tool or test equipment its article number or identification number was also added to the list. The list was then brought to be discussed and confirmed by an experienced operator for that specific product. The reason for making the list from work instructions instead of only discussion with the operator was mainly due to the below following two reasons.

1. To give the authors a deeper insight into the detail level of different work task. This was necessary to enable the right questions being asked once confirming the list with the operators, to ensure nothing was forgotten.

2. The summarised list was easier to bring to the operators instead of the already existing work instructions, that could be several pages long and difficult to follow. The shorter and more condensed lists enabled easier communication.

For almost all products produced within the SPM, one operator is responsible for all processing steps for one product from it arrives to Green unit until it is ready for delivery. Because of this, and the fact that work rotations are not being used, one operator is usually stationed with one product for a longer period of time and becomes the sole expert of that product at that time. Therefore, the final precedence list of work task for each process step was usually decided with only one operators opinion taken into consideration. The only products were more than one operators opinion has been evaluated are at 1360, 1068, 1379 and 1399 of the SPM, where smaller assembly lines has been attempted and therefore more operators are currently up to speed on the product.

The finalised precedence list considered what must happen before or after each other in the work task sequence but also the best practice in assembly sequence.

5.3.2 Testing equipment process times

Once data had been collected for both measured process times and registered process times in T-log, a decision had to be made on which time to use in the standards. The collected times, from stopwatch estimations and from T-log, was compared with each other for each test. For all 34 tests, an estimated average test process time was decided to be used, depending on how the test was functioning. If the measured and logged time were similar, an average was taken from all the collected times. If there were big differences between the logged and measured time, an average of the measured times where used. The reason for this is that for some tests the test time recorded is not representative. For example, below to activities makes logged process time vary greatly, even though the test is finished. In these cases, measured times were used.

1. When operator manually needs to check or do something in the middle of the test.
2. When the test requires the product to be scanned at the end of the test before the test is ready for the next product.

Table B.2 in appendix B shows each test specific process time, if it has any manual handling during the test, where the average was collected from, and how many measurements the average is based on.

Cycle times
Cycle times for each test was then calculated depending on how many products the test could process at a time.

5.3.3 Construction of Work standards in Avix software

Before beginning the constructions of standards in Avix, a three-level categorisation of work tasks was established. An element is the lowest level of a work task. It is part of a movement that is required for a specific task. A task is quite simply a task; to assemble a component, to mount a component, to adjust something etc. The highest level of a work task is a process step. Process steps are for example, Assembly, Through-hole mounting , Pre-functional test, Wave soldering.

Work procedure when creating a standard

1. *Deciding on a best practice.* This was made according to the section "Deciding on work standards". The practice may differ in how many products that are handled per cycle. For example, some products has THM one-by one, while other products, with smaller amount of components, has THM for 3-4 products per cycle.
2. *Setting a process step structure in Avix..* Figure 5.2 shows how the process step sequence of a product can be built up. In this case, the product is 1360-502 and one of its process steps are the THM step. THM is in this case a grouped process step consisting of THM 1 and THM 2. THM 1 in turn consist of work task but at this stage, these have not yet been created.
3. *Video analysis and creating standards for process steps.* Each process step is built up by the best practice work task order that decided on with the operator but also by method improvement potentials found when analysing the video

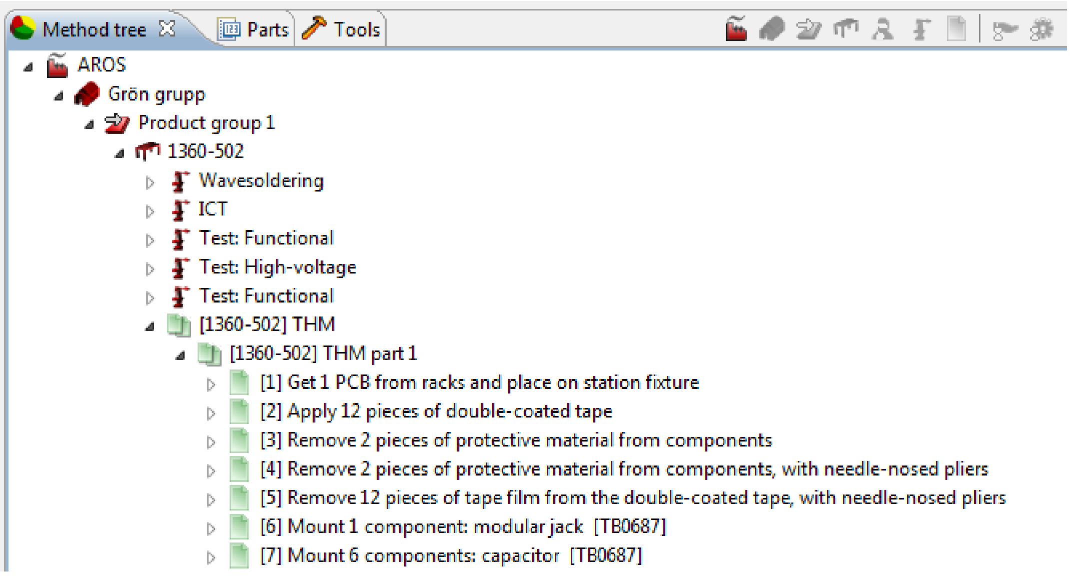


Figure 5.2: Avix structure

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material. For example, material and tools were usually placed very far away from the operator working on the workstation. It was then assumed that they could be placed within 10-45cm reach in the final layout suggestion.

4. *Adding process equipment time data.* The estimated cycle times for testing equipment, wave soldering and coating were added to machine resources in Avix, see the red and black symbols in 5.2. Each process equipment task requires manual handling before and after the automated parts of the process step and theses task were hence allocated to both machine resource and to an operator resource.

Explanation of work task levels in Avix

- Processing step-highest level. THM 1 in figure 5.2 is a process step.
- Work task-mid level. In figure 5.2, seven of the work tasks of THM 1 can be seen.
- Element-lowest level. See figure 5.3. Here, the expanded task is built up by three elements: GET, USE, PLACE.

Two ways of creating work task in Avix

- SAM analysis. SAM analysis work tasks were made either in the process library or in the main Avix tree. SAM analysis is easily made as figure 5.4 shows.
- Estimating times from video material or stopwatch measurements.

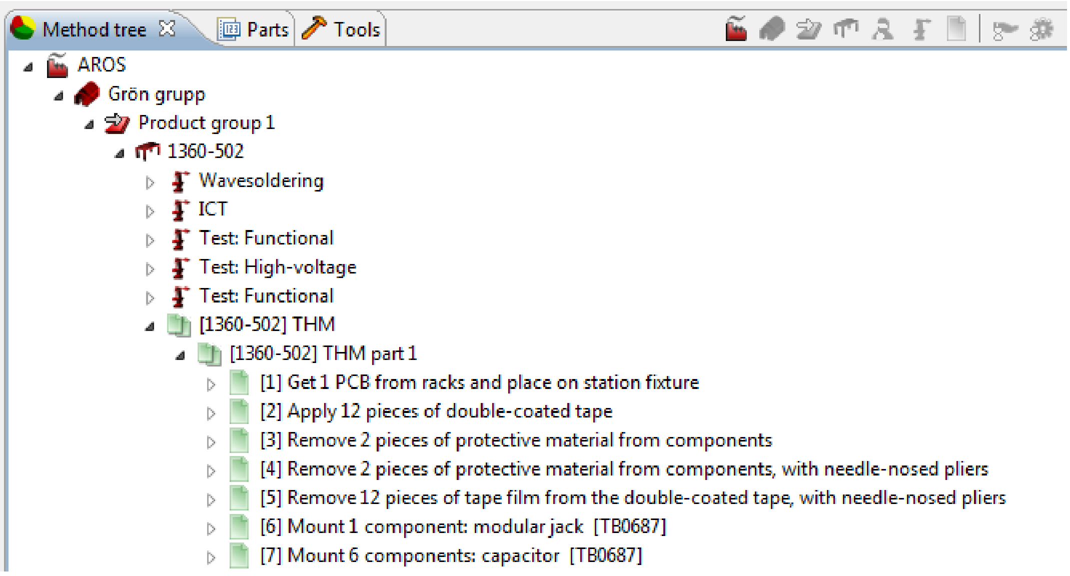


Figure 5.3: Elements and work tasks

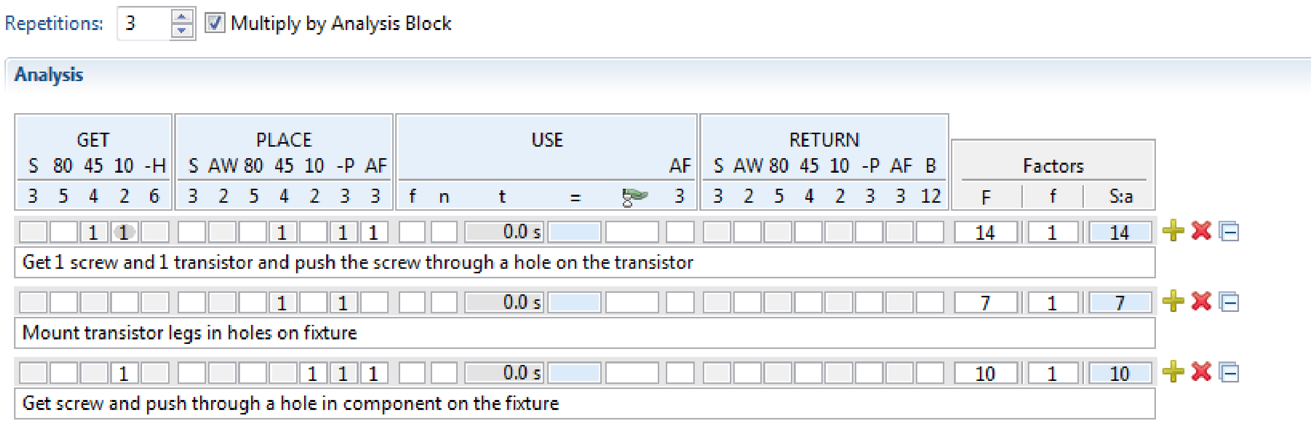


Figure 5.4: SAM-analysis in Avix

Using the process library in Avix

When a good understanding of processing steps and work tasks had been generated, it became obvious that a lot of task were very similar to each other. There were tasks that could be directly copied but others needed to be modified slightly. For this purpose, the process library in Avix was used in order to re-use already created elements and tasks. See figure 5.5 how the process library was categorised into what type of activity was made, to easily locate representative tasks and elements.

In order to ensure that they method of constructing standards and creating tasks in Avix, the authors of the thesis began with constructing one full product standard together. After this, the authors analysed one product each until all products had been constructed.

Estimated times

For most manual work, SAM has been the method to determine standard times.

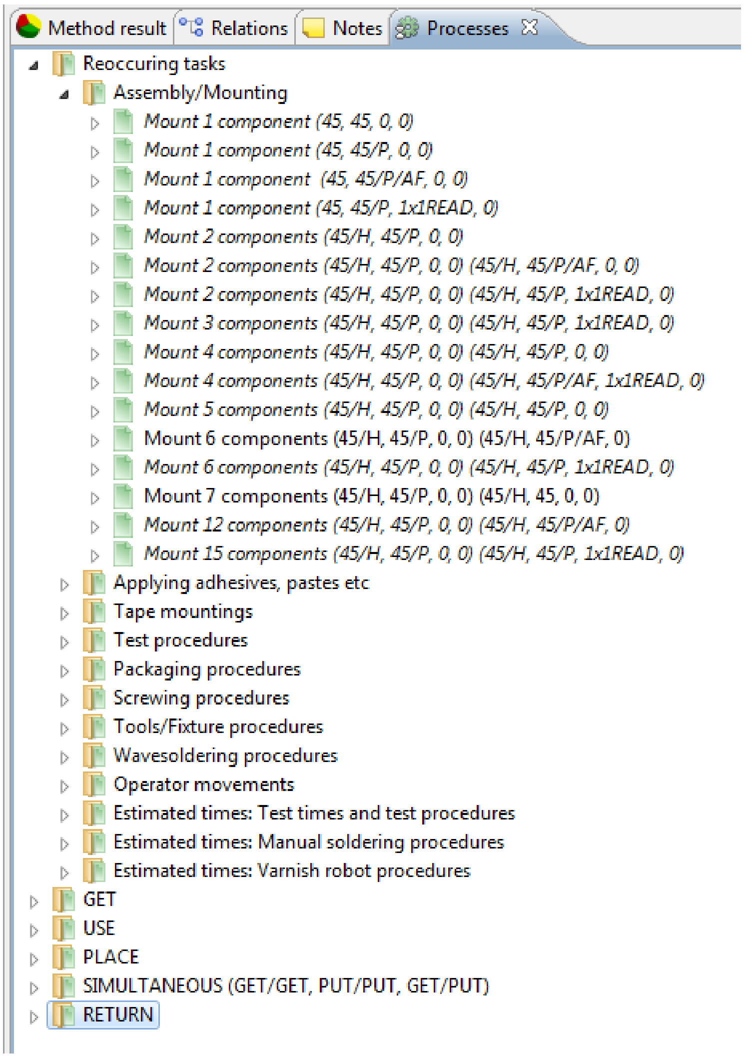


Figure 5.5: Process library

However, in some cases it was difficult to apply and judged to give an unfair representation of the time actual required. For example of when stopwatch measurements were used instead of SAM can be seen in figure 5.6

5.4 Verification of work standards through live tests

Two live test where conducted during the course of project, to see how the calculated standard times from Avix correlated to the reality. The live tests were performed on 1360-502. Both live test was arranged so that the operator would have all needed material and tools within the distance of 10-45cm, according to the created work standard. The operators working on the two live tests were not the same but all where experienced and familiar with the processes and therefore considered to be able to work at a standard performance rate. For both tests, the operators were asked to work according to the new standard a few practice runs where made. Both

Work tasks estimated from film or stopwatch		
Type of work task	**Specific work task example**	**Reason**
Handling cables	Plug in/Plug out cables that are difficult to manage. In both testing and in assembly.	A lot of hand movements and adjustments that may vary a lot from cycle to cycle. Due to unsteady material/equipment/tools, concealed sight of the work task or need of operator judgement.
Packaging	Folding cardboard, folding plastic bags etc.	
Manual tests	Display adjustments, Switch adjustments etc.	
Manual soldering	Any type of manual soldering	
Handling adhesives	Removing protective film, placing adhesive tape, etc	

Figure 5.6: Categorisation of work tasks when stopwatch times where used

live test were recorded due to the fact that disturbance and deviations always happen, regardless of preparations. By recording the whole test these deviations could then easily be identified.

During the test, the operators did not have to attend any personal needs nor showed any signs of fatigue and hence all disturbances can be assumed to be due to unforeseen events.

5.4.1 Live test 1

Preparation
The first live test was conducted in week 12, middle of March 2015, and the objective was to verify that the method used to build work standards provided realistic times. This was thought to be important since neither of the thesis authors are certified SAM analysts. It was decided to look at each workstation separately and not follow one product through the whole flow. This was judged to be the most representative since the processing steps in standard were designed to always start and finish with a clean break.

The operators working during the live tests were informed that the results would be used to confirm how the ideal times from the work standards corresponded with the reality. They were also informed of the importance to work according to the standard, even if it did not correlated to how they preferred to work. Prior to the test, each stations new work work standard had been printed. Together with each operator, the authors individually went through the instructions and answered any questions that could arise. The operators were then left to practice the new way of working for approximately five products before one product at each station was video recorded.

The video recordings where then analysed with the aid of Avix. All measured time for work tasks were noted, as well as obvious disturbances such as dropping of components and re-grasping components. From this, a net time was calculated according to 5.1. The discrepancy was then calculated according to 5.3

$$Net\ time = Measured\ time - Tot\ Disturbance \tag{5.1}$$

$$Discrepancy = \frac{(Net\ time - Ideal\ time)}{Ideal} \tag{5.2}$$

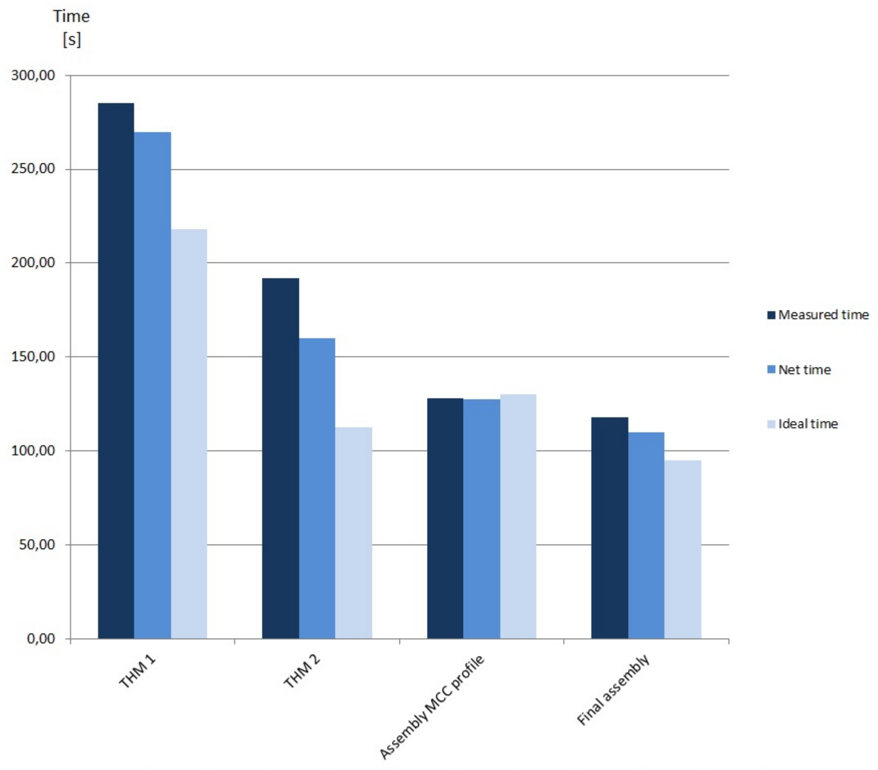


Figure 5.7: Live test 1 results

Results

The results from live test 1 can bee seen i graph 5.7. It can be seen that the discrepancy for the THM processing steps were much higher then for the other ones. It was easy to state that this was due to a lot time being spent on placing a component correctly in the hand to be able to mount it an the right position. The weighted average discrepancy for THM 1 and THM 2 resulted in 32.0 % and the main parts of this time is spent on component corrections in the hand or on the product. The reason for the final assembly being high is due to the fact that it contains both THM-similar mountings but also more common assembly task like screwing and easy placements.

The results of the discrepancies confirmed that the way of constructing lead times were fair, based on the assembly of the MCC. Here, the net time was though slightly faster then the ideal time but in turn, it could be noted that the operator actually seemed to work faster then standard performance rate.

5.4.2 Live test 2

Preparation
The second live test was conducted in w.19, beginning of may 2015, and the objective was to investigate if the discrepancy at the THM-stations from live-test 1 could be decreased by further method improvements. Except from a different objective, live test 2 was performed in the same manner as live test 1. A THM-discrepancy factor, a weighted average, was estimated for each THM station by multiplying number of work tasks (WT) by the station discrepancy (D). From this, a total THM compensation factor (CF) could be established according to 5.3 to be used in the balancing.

$$CF_{\text{THM tot}} = \frac{(WT_{\text{THM1}}\ x\ D_{\text{THM1}}) + (WT_{\text{THM2}}\ x\ D_{\text{THM2}})}{(WT_{\text{THM1}} + WK_{\text{THM2}})} \tag{5.3}$$

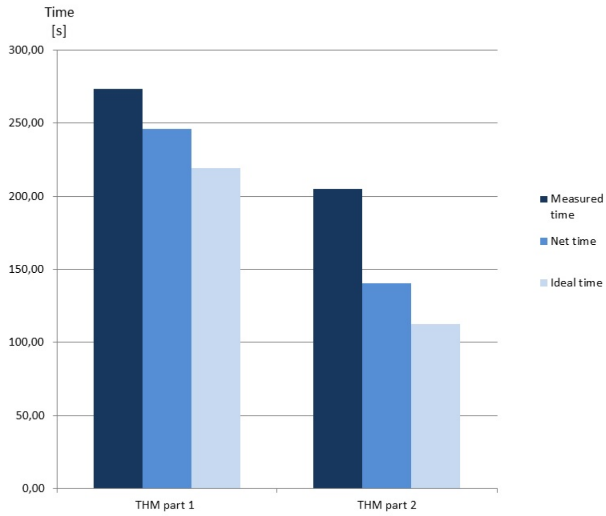


Figure 5.8: Live test 2 results

Results
After the method improvements, with a new material facade that enables the operator to pick up a component and mount it directly onto the product, the weighted average discrepancy decreased to 17.6 %. The discrepancy from the earlier THM was 32.0 %. This was further on used as the compensation factor in the balancing to establish more realistic process times for all THM processing steps. The full results of Live test 2 can be seen figure 5.8.

5.5 Construction of ideal lead times

All products ideal lead times have been calculated for the 15 products of the SPM, if they where to be produced in the current state layout. The lead times has been calculated by adding the work standard times for manual labour, test times and process times. Also, the current state conveyor times and after-coating drying times have been added. Each process separate contribution to the lead time can be seen in table B.1 in appendix B and are illustrated in figure 5.9. As seen from the graph, it is the drying time that takes up most of the time of the ideal lead time.

Figure 5.10 shows the ideal lead times when all drying times are excluded. As can bee seen from the graph, roughly half of all products lead time consist of transport times and process equipment times. Therefor, it will be important to utilise the operator during test times and to eliminate transports as much as possible in the final layout suggestion.

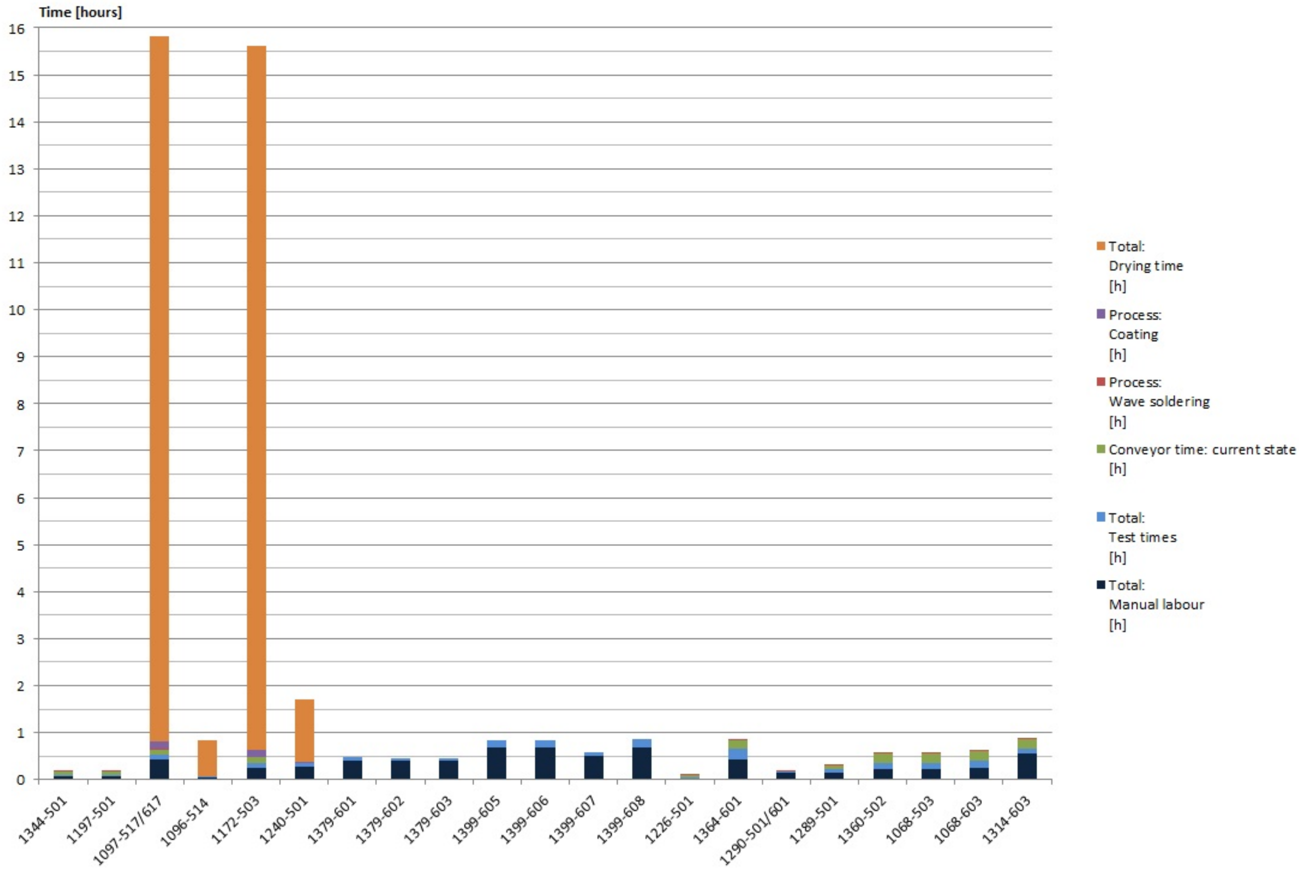


Figure 5.9: Graph illustrating ideal lead times, in hours, based on current state layout

5.6 Current production planning

Once the ideal lead time were known for the SPM, it was desired to know their total needed production time. The production leader, who is responsible for weekly planning, was asked to plan the production for the SPM. The planning is based on her own knowledge of the system, which is the way the production is normally planed. The result can be seen in table 5.11. This became the reference time to be used when calculating the current state capacity.

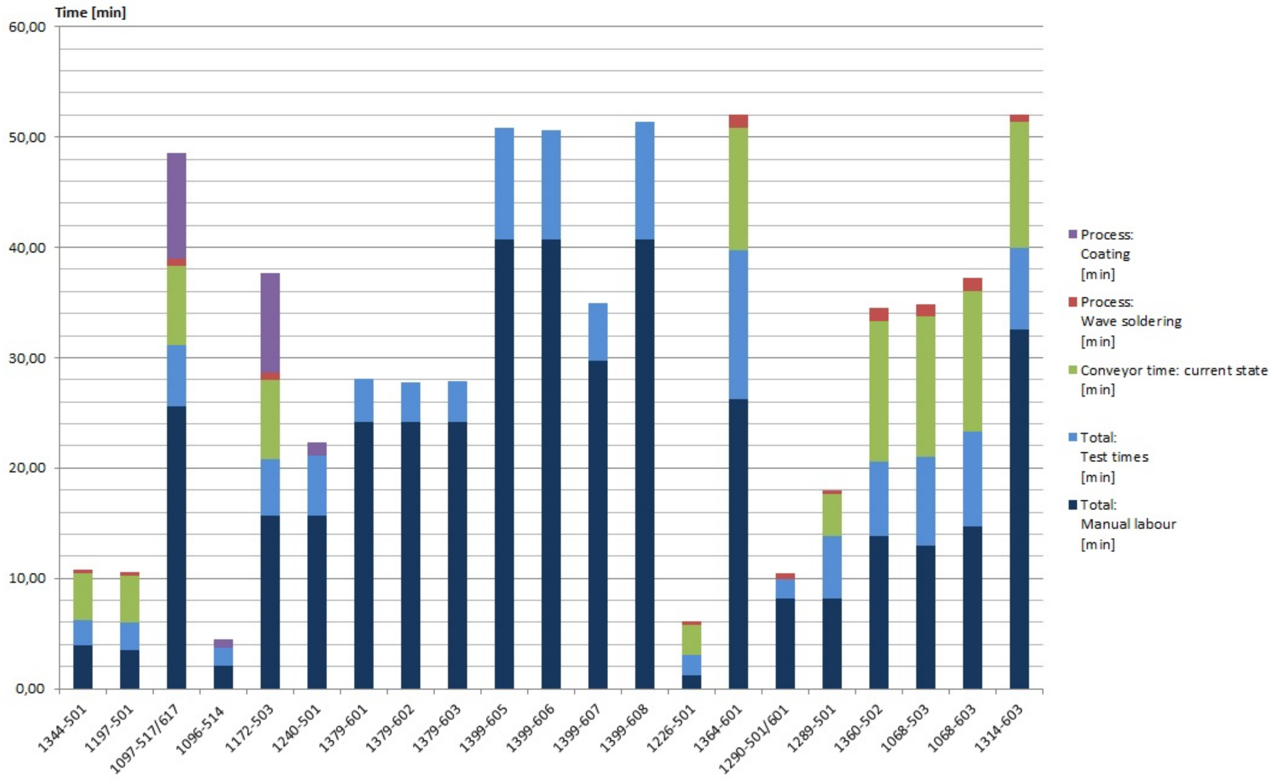


Figure 5.10: Graph illustrating ideal lead times, in minutes, based on current state layout. Drying times not included.

Figure 5.11: Current needed production time for SPM

Current State Needed Production time for product mix Week 19			
Product	**Shifts**	**Number of Operators**	**Needed production time [h]**
1344-501	4	1	31
1197-501			
1097	5	1	38,75
1096			
1172			
1240-501	1	1	7,75
1379/1399	5	2	77,5
1226	2	1	15,5
1364,1290,1289	5	1	38,75
1360/1068	5	5	193,75
1314-603	5	1	38,75
ICT production time allocated to product mix (Allocated through ICT equipment process times)	4	0,47	14,57
Production time per shift [h]			7,75
Current State Needed Production time [h]			456,3

6
Solution

In this chapter, the results from step five in the Methods engineering methodology is presented. The ideal solutions, of the selected work system to be improved, is presented. This is illustrated by the balancing of the created work standards along with a layout suggestion and finally, the capacity increase the solution will bring.

6.1 Product families

From the PFA, five clear distinctions of product families could be found.

- Products utilising the wave soldering machines
- Products only requiring manual soldering and assemblies
- Products utilising the ICT equipment
- Products utilising the coating robot
- Products that share the same specific functional test, the WK-test

The wave soldering process was a clear divider between in the product flows, since it could be viewed as the pacemaker of the flow. The flow before the wave soldering process was named the Alpha-flow, which consist of products from all product families except the products only needing manual soldering.

After the wave soldering process, products split up to their respective product family. The only product not having one clear product family was 1097, which required both the ICT and coating robot. It was decided that the ICT provided more of a constraint in the production and therefore the 1097 was placed to belong to the ICT family.

To more easily separate the product families they where given names:

- ALPHA: Products utilising the Wave soldering machines
- BETA: Products utilising the ICT equipment
- GAMMA: Products needing the coating robot
- DELTA: Products that share the same specific functional test, the WK-test
- EPSILON: Products only requiring manual soldering and assemblies

6.2 Balancing

In this section, the balancing itself and its related work tasks are explained. The balancing builds on the created work standards.

6.2.1 Establishing cycle times

The created work standards vary in when processing steps process one or more products per cycle and so these had to be transformed to cycle time per product in order to balance correctly. Avix supports this by a change in task frequency, which decreases or increases the cycle time proportionally to the batch size of the processing step.

Wave soldering
The wave soldering capacity is known for each wave soldering frame. It was assumed therefore that each frame will only carry one panel through the wave soldering process. This to enable easier handling when changing the frequency and also for quality reasons. During the time spent on the production floor, it was observed that sometimes when two boards were placed next to each other in a frame, some component were not soldered properly. The panel then had to be sent through the soldering machine again.

Testing equipment cycle times
Some test handle more than one product at a time and so the performed measurements were as well. Therefore, the frequency of these tests were changed in order to transform the process time to a cycle time.

6.2.2 Testing equipment yields

Since the testing equipment is unreliable, it was decided that two balancing scenarios were required. One ideal case and one where test yields where compensated for in order to show the impact of the unreliability. It was decided to adjust each test frequency with the FPY, which is one of the two yields that Aros measures. Both yields has flaws and neither will correctly represent the system but the FPY was chosen. The motivation for this is that if the system can be balanced and meet the required takt, with only products that pass each test the first time, the balanced suggestion would work.

In cases where the cycle time had already been adjusted, due to batch sizes in process equipment, the new frequency was calculated through multiplication of both percentages.

It was assumed that the compensated balancing suggestion would still be within the required takt time and therefor, once the ideal balance case was completed, only the test yield % was added to show the difference in cycle time, but no re-balancing was done. This to avoid sub-optimisation.

6.2.3 Process equipment

As stated in the current state, it varies a lot in how the testing equipment are used. Same testing equipment can be used for a few different products, by changing jig. Also, the same testing equipment can be used as both pre-funtional test and a final-functional test for the same product. This has becomes a limitation when planning the final production flow since these test cannot be at two physical locations at the same time. Due to this, the flow has to be adapted so that products that require test with this limitation re-visits the work station where the test unit is finally placed.

6.2.4 The iterative balancing process

As described in the Method chapter, each product family was balanced individually and with the use of ECRS. This turned into an iterative process, where each iteration contained the below following four steps during each cycle.

1. **Calculation of Takt time**
   Takt time was calculated according to the SPM.
   Available production time was decided by the authors to be 6 hours per shift, with five shifts per week. This decision was based on a discussion with the production leader where it was stated that it might be a good idea since the Albany line currently has this setup and it is judged to work well there.

2. **Balancing of each product**
   Firstly, all products were balanced individually. At this stage, it became apparent that the cycle times of the testing equipment would become a big constraint. Operators should be utilised as much as possible during these cycle times and should be kept working instead of waiting. Due to the long cycle times of the testing, balancing of manual work task were made as evenly as possible with them. An efficient flow between workstation was attempted to be achieved, while still utilising operators during automated cycle times.

3. **Balancing of each product family**
   Once all products within a product family had been balanced, the product family as a whole was balanced with aim of utilising all operators utilisation.

4. **Evaluation**
   Once all product families had been balanced, the results were evaluated. If there were overcapacity and low operator utilisation within a product families it was evaluated if they could be combined and the process was started again.

Finally, it was judged that only three production lines were necessary. The balancing results only presents these final three production lines. The lines are named ALPHA, BETA and GAMMA.

All three production lines are balanced as mixed model lines, where more than one product can be produced at the same time. However, due to uneven cycle times between workstations and the set up times it becomes difficult to run the lines as pure mixed-model lines. In the end, the lines should be run as multi-model lines but with small batch sizes.

6.2.5 ALPHA line

The ALPHA line is the THM line, on which 12 products are run. The line consist of only THM of components, which is the processing step that is required before the wave soldering process. Only one case for the ALPHA-line balancing is presented, a realistic case. This since no test yields can be added. From live test 2 it was concluded that a discrepancy of 17.6% should be used for all THM work tasks. It was used in order to give a more realistic balancing suggestion of these work tasks. It is balanced according to the SPM seen in table 6.1

Table 6.1: SPM percentage for ALPHA line

Product	SPM [%]
1360-502	21,7
1068-503	7,3
1068-603	7,2
1314-603	3,1
1344-501	8,6
1197-501	12,2
1226-501	26,9
1364-601	2,4
1290-501	2,4
1289-501	2,4
1097-517	3,7
1172-503	2

Figure 6.1 illustrates the final balance suggestion for the ALPHA line. As can be seen from figure 6.1 the ALPHA line consist of three workstations and three operators. For three of the products: 1360-502, 1068-503 and 1068-603, the THM steps has been split between two operators. These two operators are always stationed at this line. When these three products are run at the BETA line, only three workstations are needed there, as will be explained further in the next section. Because of this, Operator 4 from the BETA line becomes an extra resource that can be used to perform THM and buffer products. This is done at the two empty workstations at the BETA line, when their high-runners are produced. The operator utilisation can be seen in figure 6.2.

The grey line above each workstation, seen in figure 6.1 is the lines required takt time. The ALPHA line required takt time was 132 s. The blue line above the wave soldering station illustrates the capacity maximum that can be dedicated to the SPM, which is 64% of the resources max capacity. As seen, the current utilisation is well below in the balance suggestion. As can bee seen from the graph, the ALPHA

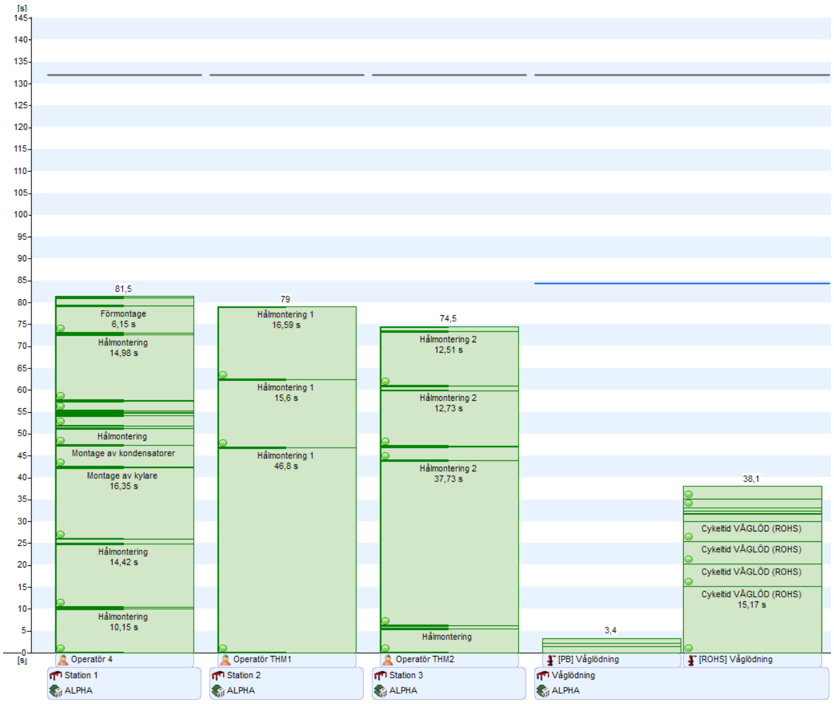


Figure 6.1: Balance graph over the ALPHA line

Namn	Tid: Max	Tid: Skillnad	Utnyttjandegrad: Operatör Medel	Utnyttjandegrad: Maskin Medel	Takt: Effektivitetstakt	Resurser: Operatörer	Resurser: Maskiner
AROS	81,5	-46,4	59%	25%	-	3	2
Grön grupp	81,5	-46,4	59%	25%	-	3	2
ALPHA [THM]	81,5	-46,4	59%	25%	132,0	3	2
[1] Station 1	81,5	-50,5	62%	-	132,0	1	0
Operatör 4	81,5	-50,5	62%	-	132,0	1	0
[2] Station 2	79,0	-53,0	60%	-	132,0	1	0
Operatör THM1	79,0	-53,0	60%	-	132,0	1	0
[3] Station 3	74,5	-57,5	56%	-	132,0	1	0
Operatör THM2	74,5	-57,5	56%	-	132,0	1	0
Våglödning	38,1	-46,4	-	25%	84,5	0	2
[PB] Våglödning	3,4	-81,1	-	4%	84,5	0	1
[ROHS] Våglödning	38,1	-46,4	-	45%	84,5	0	1

Figure 6.2: Operator and test utilisation of the ALPHA line

line currently performs at a cycle time of 81.5 s, which is just above half the required takt time. It could therefore easily perform below the required takt time, using only two operators. This was decided against due too the below following two reasons:

1. Operator 4 of the BETA line was poorly utilised and by adding this operator to also work at the ALPHA line, the utilisation increased.

2. The aim of this thesis was to increase the production flow of wave soldered products and therefore, the authors suggest that the wave soldered products of Orange unit should also be added to the ALPHA and BETA production lines. The overcapacity was therefore left on the line in order to show that there is room for the products of the Orange unit.

6.2.6 BETA-line

The BETA line is the combination of the previously separated BETA, DELTA and GAMMA lines. The BETA line now contains all of these three product families. On the Beta line, 14 different products are run and the line consist of for example manual assemblies, testings and final packaging. Many different activities at once happen at this line. It consists of six workstations and six operators. Some workstations will be revisited by some products, due to having shared testing units in different test types. The operator in charge of the coating process will have much spare time during the processing times. This operator has therefore also been given the task of components preparations, for all three lines.

Since the BETA line involves testing, two balancing cases have been completed. One ideal and one with test yields taken into consideration. For both cases, the takt time has been calculated to 126 s and they have been balanced according to the SPM seen in table 6.2

Table 6.2: SPM percentage for BETA line

Product	SPM [%]
1360-502	13,8
1068-503	4,7
1068-603	4,6
1314-603	2
1344-501	5,5
1197-501	7,8
1226-501	17,2
1364-601	1,6
1290-501	1,6
1289-501	1,6
1097-517	2,3
1172-503	1,2
1096-514	2,4
Comp. Prep 1379-601	0,5
Comp. Prep 1364-501	1,6
Comp. Prep 1097-601	2,3
Comp. Prep 1314-603	2
Comp. Prep 1360-502	13,8
Comp. Prep 1068-503	4,7
Comp. Prep 1068-603	4,6
Comp. Prep 1172-503	1,2
Comp. Prep 1172-503	2,3

Ideal Case
The balance graph of the ideal case BETA line can be seen in 6.3. Workstation cycle time varies between 27.9 s-62.9 s, with workstation 1, 2 and 5 having the highest

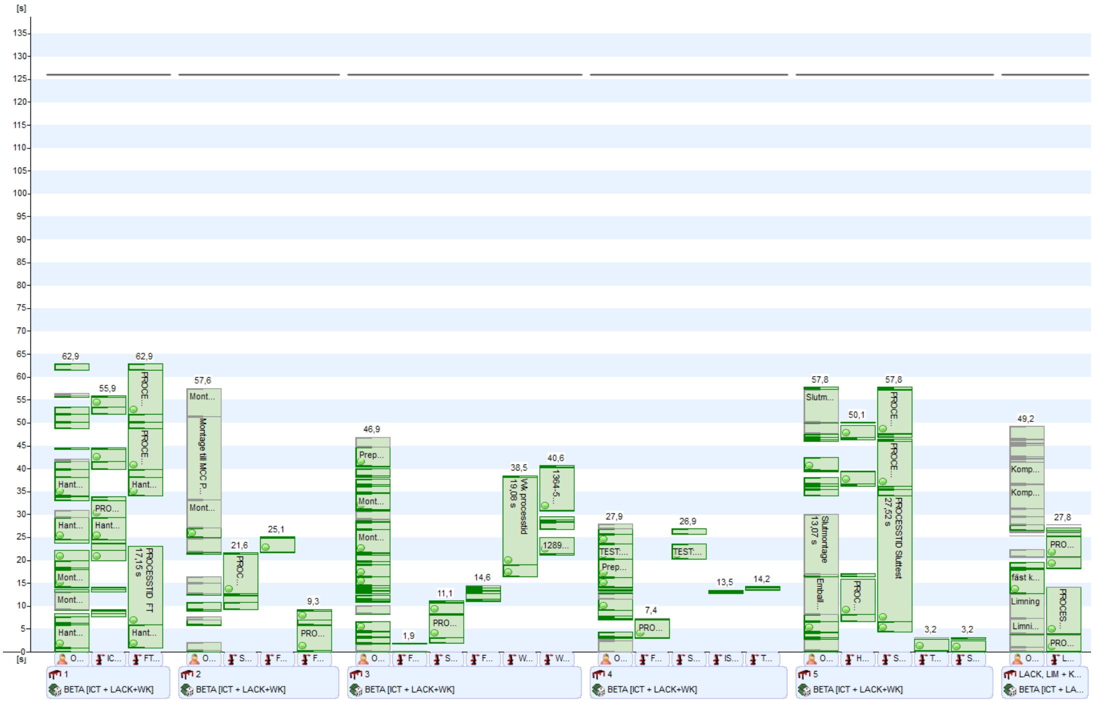
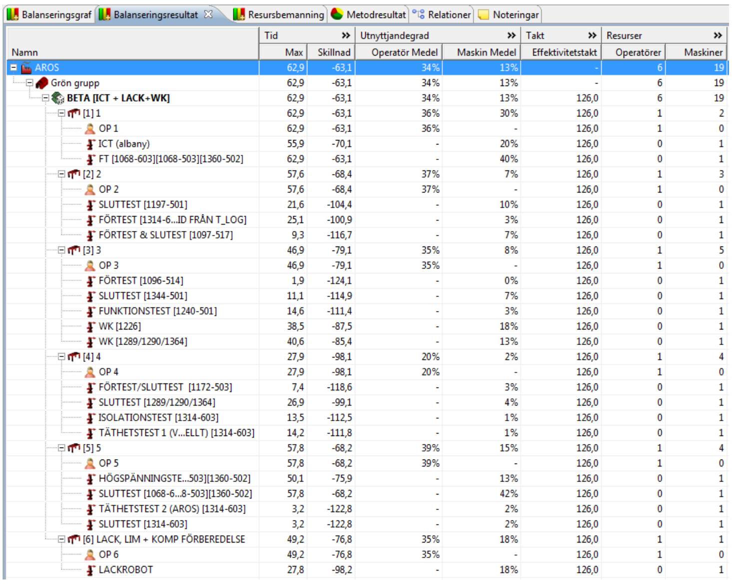


Figure 6.3: Balance graph of the ideal case BETA line

cycle times. This is due to that these stations are where the high runners are being processed, therefor making them give a higher cycle time impact when balancing the production mix.

To as high extent as possible, similar work task for different product has been tried to be placed at the same workstation. However, the thing that most emphasis was put on was to even out the operators utilisation, as seen in figure 6.4. Therefore, products from the WK product family and the Coating product family that do not come in as high volumes as products in the ICT product family, have been shifted one step in the production line. They have their first workstation on the line at station 2. Which station that is utilised by which product can bee seen in the product/station matrix illustrated in figure 6.7.

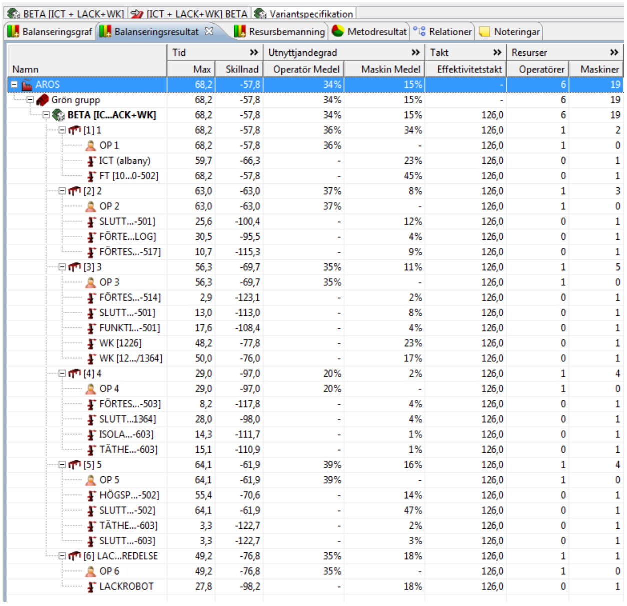
Figure 6.4: Operator and test utilisation of the ideal case BETA line



Balanseringsgraf | Balanseringsresultat | Resursbemanning | Metodresultat | Relationer | Noteringar

	Tid		Utnyttjandegrad		Takt	Resurser	
Namn	Max	Skillnad	Operatör Medel	Maskin Medel	Effektivitetstakt	Operatörer	Maskiner
AROS	62,9	-63,1	34%	13%	-	6	19
Grön grupp	62,9	-63,1	34%	13%	-	6	19
BETA [ICT + LACK+WK]	62,9	-63,1	34%	13%	126,0	6	19
[1] 1	62,9	-63,1	36%	30%	126,0	1	2
OP 1	62,9	-63,1	36%	-	126,0	1	0
ICT (albany)	55,9	-70,1	-	20%	126,0	0	1
FT [1068-603][1068-503][1360-502]	62,9	-63,1	-	40%	126,0	0	1
[2] 2	57,6	-68,4	37%	7%	126,0	1	3
OP 2	57,6	-68,4	37%	-	126,0	1	0
SLUTTEST [1197-501]	21,6	-104,4	-	10%	126,0	0	1
FÖRTEST [1314-6...ID FRÅN T_LOG]	25,1	-100,9	-	3%	126,0	0	1
FÖRTEST & SLUTEST [1097-517]	9,3	-116,7	-	7%	126,0	0	1
[3] 3	46,9	-79,1	35%	8%	126,0	1	5
OP 3	46,9	-79,1	35%	-	126,0	1	0
FÖRTEST [1096-514]	1,9	-124,1	-	0%	126,0	0	1
SLUTTEST [1344-501]	11,1	-114,9	-	7%	126,0	0	1
FUNKTIONSTEST [1240-501]	14,6	-111,4	-	3%	126,0	0	1
WK [1226]	38,5	-87,5	-	18%	126,0	0	1
WK [1289/1290/1364]	40,6	-85,4	-	13%	126,0	0	1
[4] 4	27,9	-98,1	20%	2%	126,0	1	4
OP 4	27,9	-98,1	20%	-	126,0	1	0
FÖRTEST/SLUTTEST [1172-503]	7,4	-118,6	-	3%	126,0	0	1
SLUTTEST [1289/1290/1364]	26,9	-99,1	-	4%	126,0	0	1
ISOLATIONSTEST [1314-603]	13,5	-112,5	-	1%	126,0	0	1
TÄTHETSTEST 1 (V...ELLT) [1314-603]	14,2	-111,8	-	1%	126,0	0	1
[5] 5	57,8	-68,2	39%	15%	126,0	1	4
OP 5	57,8	-68,2	39%	-	126,0	1	0
HÖGSPÄNNINGSTE...503][1360-502]	50,1	-75,9	-	13%	126,0	0	1
SLUTTEST [1068-6...8-503][1360-502]	57,8	-68,2	-	42%	126,0	0	1
TÄTHETSTEST 2 (AROS) [1314-603]	3,2	-122,8	-	2%	126,0	0	1
SLUTTEST [1314-603]	3,2	-122,8	-	2%	126,0	0	1
[6] LACK, LIM + KOMP FÖRBEREDELSE	49,2	-76,8	35%	18%	126,0	1	1
OP 6	49,2	-76,8	35%	-	126,0	1	0
LACKROBOT	27,8	-98,2	-	18%	126,0	0	1

Figure 6.5: Operator and test utilisation of the Realistic case BETA line



BETA [ICT + LACK+WK] | [ICT + LACK+WK] BETA | Variantspecifikation

Balanseringsgraf | Balanseringsresultat | Resursbemanning | Metodresultat | Relationer | Noteringar

	Tid		Utnyttjandegrad		Takt	Resurser	
Namn	Max	Skillnad	Operatör Medel	Maskin Medel	Effektivitetstakt	Operatörer	Maskiner
AROS	68,2	-57,8	34%	15%	-	6	19
Grön grupp	68,2	-57,8	34%	15%	-	6	19
BETA [IC...ACK+WK]	68,2	-57,8	34%	15%	126,0	6	19
[1] 1	68,2	-57,8	36%	34%	126,0	1	2
OP 1	68,2	-57,8	36%	-	126,0	1	0
ICT (albany)	59,7	-66,3	-	23%	126,0	0	1
FT [10...0-502]	68,2	-57,8	-	45%	126,0	0	1
[2] 2	63,0	-63,0	37%	8%	126,0	1	3
OP 2	63,0	-63,0	37%	-	126,0	1	0
SLUTT...-501]	25,6	-100,4	-	12%	126,0	0	1
FÖRTE...LOG]	30,5	-95,5	-	4%	126,0	0	1
FÖRTES...-517]	10,7	-115,3	-	9%	126,0	0	1
[3] 3	56,3	-69,7	35%	11%	126,0	1	5
OP 3	56,3	-69,7	35%	-	126,0	1	0
FÖRTES...-514]	2,9	-123,1	-	2%	126,0	0	1
SLUTT...-501]	13,0	-113,0	-	8%	126,0	0	1
FUNKTI...-501]	17,6	-108,4	-	4%	126,0	0	1
WK [1226]	48,2	-77,8	-	23%	126,0	0	1
WK [12.../1364]	50,0	-76,0	-	17%	126,0	0	1
[4] 4	29,0	-97,0	20%	2%	126,0	1	4
OP 4	29,0	-97,0	20%	-	126,0	1	0
FÖRTES...-503]	8,2	-117,8	-	4%	126,0	0	1
SLUTT...1364]	28,0	-98,0	-	4%	126,0	0	1
ISOLA...-603]	14,3	-111,7	-	1%	126,0	0	1
TÄTHE...-603]	15,1	-110,9	-	1%	126,0	0	1
[5] 5	64,1	-61,9	39%	16%	126,0	1	4
OP 5	64,1	-61,9	39%	-	126,0	1	0
HÖGSP...-502]	55,4	-70,6	-	14%	126,0	0	1
SLUTT...-502]	64,1	-61,9	-	47%	126,0	0	1
TÄTHE...-603]	3,3	-122,7	-	2%	126,0	0	1
SLUTT...-603]	3,3	-122,7	-	3%	126,0	0	1
[6] LAC...REDELSE	49,2	-76,8	35%	18%	126,0	1	1
OP 6	49,2	-76,8	35%	-	126,0	1	0
LACKROBOT	27,8	-98,2	-	18%	126,0	0	1

Worth mentioning is that the balancing of the BETA line only manage to perform under the designated takt time is if it is in the given mix. In the products individual balancing graphs only one of the 14 products produced can meet the takt time. This is due to the long cycle times.

When balancing the BETA line, focus has been on trying to achieve an efficient flow. Due to test cycle times and the inflexibility with test units, a true flow is only really possible with some products, 1360-502, 1068-503, 1068-603 and 1314-603. In similarity with the ALPHA line, the BETA line currently performs at a cycle time of 62,9, which is just below half of the takt time.

Realistic Case
The realistic balance graph of the BETA line, with test yields added, can be seen in figure 6.6. No re-balancing was needed since the line still performs well beneath the takt time. Since only the test yields that have been changed, the operator utilisation remains roughly the same, as seen in 6.4 and 6.5. The interesting thing however is that the cycle time increase with 5.3 s, from 62.9 s to 68.2, which is a 8.4% increase.

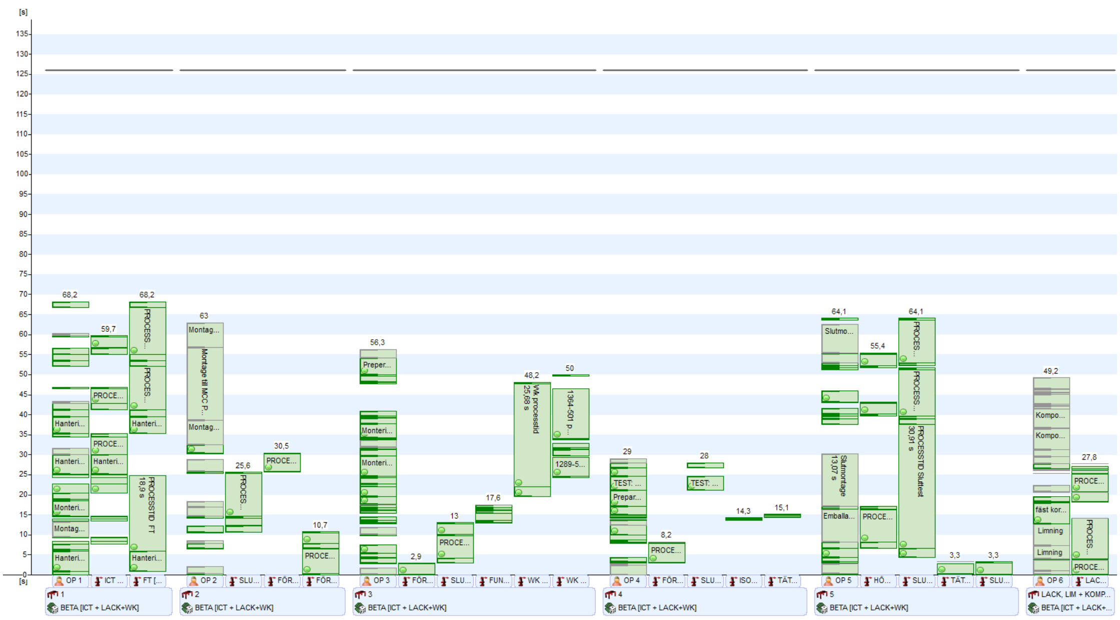


Figure 6.6: Balance graph of BETA realistic case

6.2.7 Gamma line:

The GAMMA line contains the seven products that do not go through the wave soldering processes, 1379 and 1399 and its variants. It consist of manual assemblies and testings and therefore, two balancing cases were made. For both cases, the takt time was 3600s. According to the SPM, these products were balanced with the following mix seen in table 6.3.

Table 6.3: SPM percentages for the GAMMA line

Product	SPM [%]
1379-601	20
1399-605	60
1399-607	20

Ideal Case
The ideal balance graph of the GAMMA line can be seen in figure 6.8. The cycle

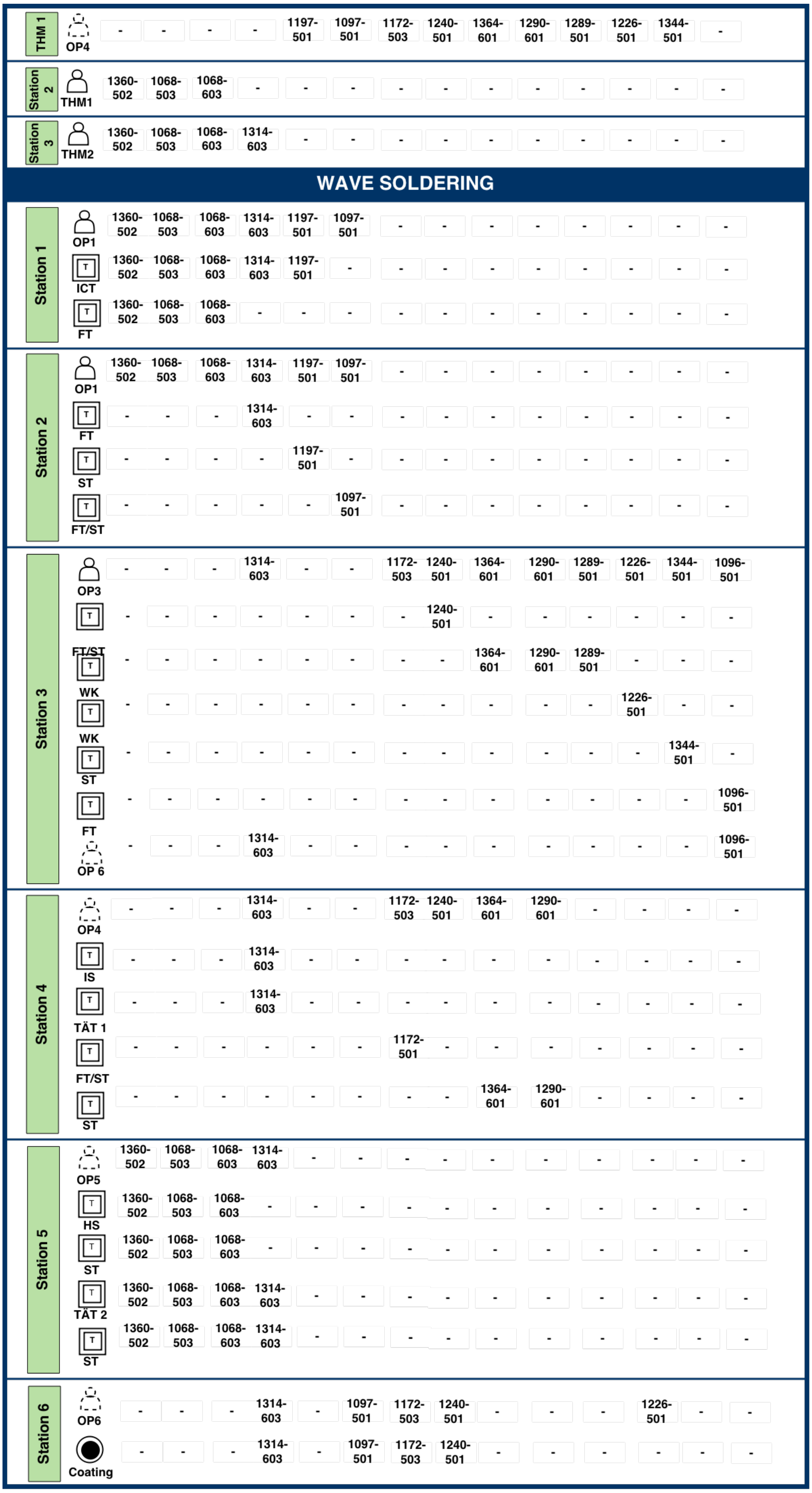


Figure 6.7: Product/station matrix

time of 848.2 s is well below the required takt time but as can be seen from figure 6.9, the operator utilisation is low.

It was therefore decided to re-balance the production flow of the GAMMA-line to only one operator. The cycle time then increased to the full lead time of the product, which is 2456 s, which is still less then the required takt time.The operators utilisation though increased from the previous 12 to 58%, as seen in figure 6.10. It is still suggested that, even though it is only operated by one operator, three workstations are required since the product requires much manual assembly and and a very time consuming test. Also, since the GAMMA line does not require the wave soldering machines, it is suggested that these products are taken over by Orange unit. Then the suggested GAMMA line with three operators can be good start to build up their production line from, since it exists a lot of over capacity.

Realistic Case

The balance graph of the realistic case GAMMA line, using one operator, can be seen figure 6.11. When adding the test yields to the the GAMMA line, the cycle time increased with 110.3 s, from 2456 to 2566.3 s, which is a 4.5% increase.

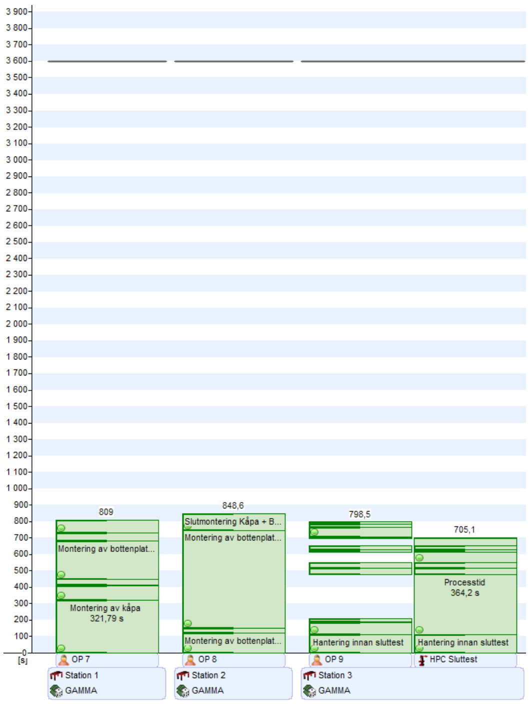
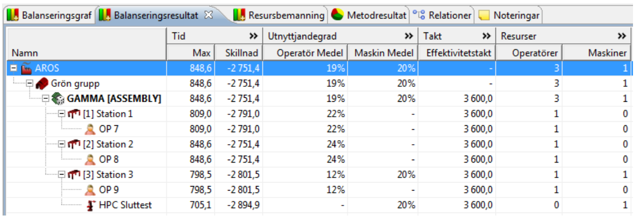
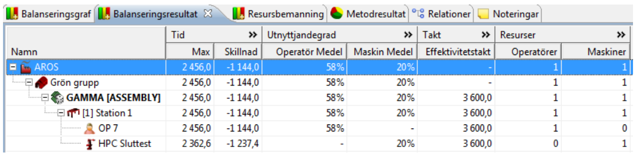


Figure 6.8: Balancing graph of the ideal case GAMMA line,3 operators



	Tid		Utnyttjandegrad		Takt	Resurser	
Namn	Max	Skillnad	Operatör Medel	Maskin Medel	Effektivitetstakt	Operatörer	Maskiner
AROS	848,6	-2 751,4	19%	20%	-	3	1
Grön grupp	848,6	-2 751,4	19%	20%	-	3	1
GAMMA [ASSEMBLY]	848,6	-2 751,4	19%	20%	3 600,0	3	1
[1] Station 1	809,0	-2 791,0	22%	-	3 600,0	1	0
OP 7	809,0	-2 791,0	22%	-	3 600,0	1	0
[2] Station 2	848,6	-2 751,4	24%	-	3 600,0	1	0
OP 8	848,6	-2 751,4	24%	-	3 600,0	1	0
[3] Station 3	798,5	-2 801,5	12%	20%	3 600,0	1	1
OP 9	798,5	-2 801,5	12%	-	3 600,0	1	0
HPC Sluttest	705,1	-2 894,9	-	20%	3 600,0	0	1

Figure 6.9: Operator utilisation for ideal GAMMA balancing, with 3 operators



Balanseringsgraf | Balanseringsresultat | Resursbemanning | Metodresultat | Relationer | Noteringar

	Tid		Utnyttjandegrad		Takt	Resurser	
Namn	Max	Skillnad	Operatör Medel	Maskin Medel	Effektivitetstakt	Operatörer	Maskiner
AROS	2 456,0	-1 144,0	58%	20%	-	1	1
Grön grupp	2 456,0	-1 144,0	58%	20%	-	1	1
GAMMA [ASSEMBLY]	2 456,0	-1 144,0	58%	20%	3 600,0	1	1
[1] Station 1	2 456,0	-1 144,0	58%	20%	3 600,0	1	1
OP 7	2 456,0	-1 144,0	58%	-	3 600,0	1	0
HPC Sluttest	2 362,6	-1 237,4	-	20%	3 600,0	0	1

Figure 6.10: Operator utilisation for ideal GAMMA balancing, with 1 operator

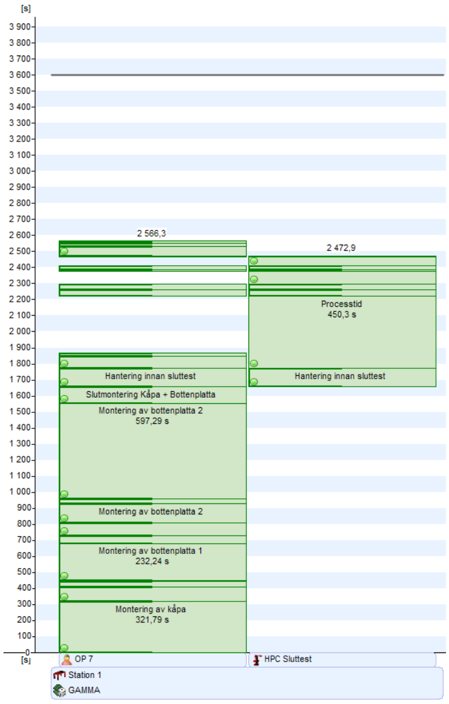


Figure 6.11: Balancing graph of the realistic case GAMMA line, with 1 operator

6.2.8 General Conditions for balancing to succeed

It is important to point out that in order to achieve the new production flow suggested above, it requires structural changes not only to the subject of the study. Green unit and the organisation of support functions must change. The most important assumptions made and requirements needed, in order for the solution to work, is summarised below. These must be fulfilled before any implementation could start.

- It is assumed that all needed material and tooling could be placed within 10-45 cm of the operator at a workstation.
- It is assumed that larger materials or containers, such as bulky components, pallets or racks, could be placed within the 80 cm distance class of SAM
- All material is supplied according to the created work standards
- All material is available when needed at the workstation
- All material not needed for the specific product produced will fit on existing shelves of the workstations table. Changeovers are required when a new product arrives

- Product sequence and batch sizes need to be determined according to which tasks take place during which test cycle time.
- Production planning need to change from being based on estimations to being based on realistic time data.
- Operators has to truly understand the importance of working according to work standards, in order to have them followed.
- Work rotations are needed in order help with motivation and to have a flexibility with the work force between the work tasks.

6.3 Layout

A future layout suggestion for the suggested production flows was made in Microsoft Visio. Here, each of the lines workstations were evaluated and mapped. Depending on the workstations work tasks, required process equipment and material, a production space was assigned. Since the aim was to not make any heavy investments, existing tables and equipment from the current state layout was used to create the future layout plan. The final suggestion of line and station placements can be seen in figure 6.12.

The purpose was to create space. This can be interpreted both as shrinking the space used by the SPM as well as creating more space for them since everything is so cramped. The suggested layout has tried to take both these aspects into consideration. The lines are placed to provide a better flow between the production department and through the whole factory. Criss-cross movement have been minimised and in a U-shaped flow has been created. Work stations within the production lines are placed to provide better flows in each line, which in turn has minimised transports drastically in both operators walking and conveyor transports. An estimated reduction in conveyor transport for each product can bee seen in figure 6.13 and the data for the estimation in table B.1 in appendix B. The transportation data of the improved state were estimated based on fix conveyor speed and from the distances from the new layout. See estimations in C.1 in appendix C. The product flows for the new layout suggestion can be seen in figure 6.14.

The suggested layout could have been squeezed into a smaller area in order to improve percentage in area reduction. It was though considered better to highlight the importance of work environment aspects. The areas of the production lines were widened so there is plenty of space to move around on for the operators, keeping buffers and handling WIP.

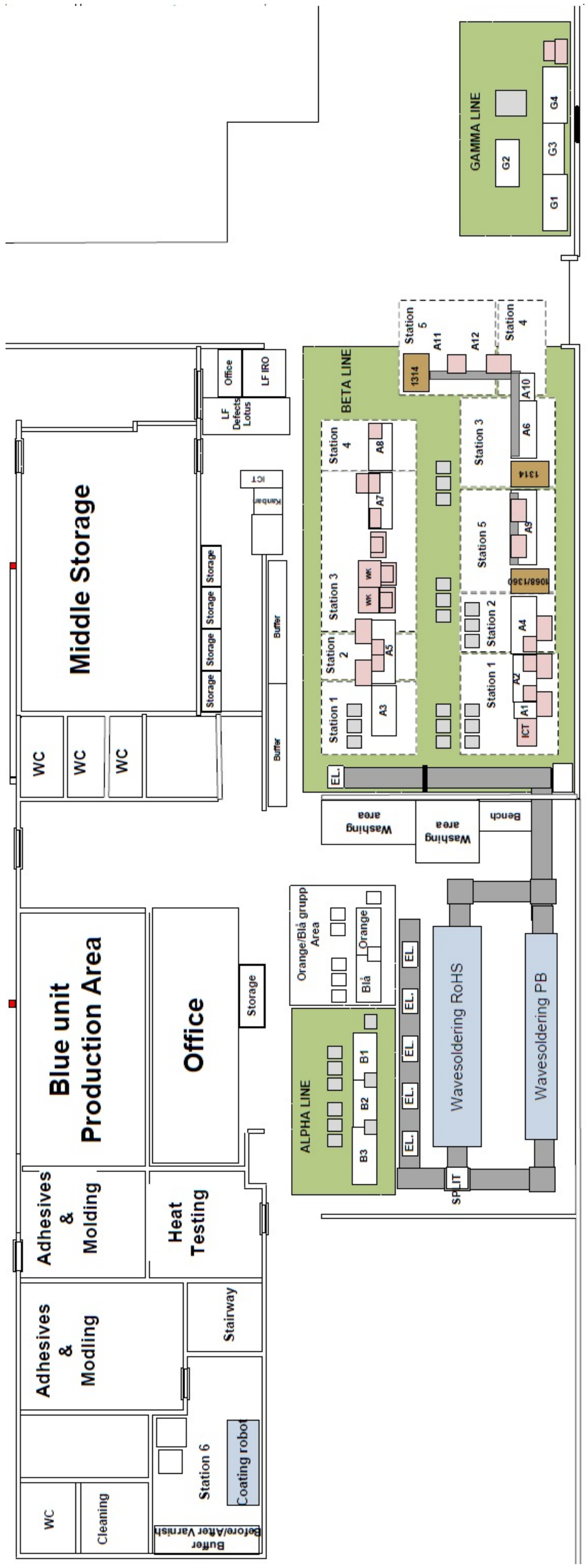


Figure 6.12: Proposed layout of lines and stations

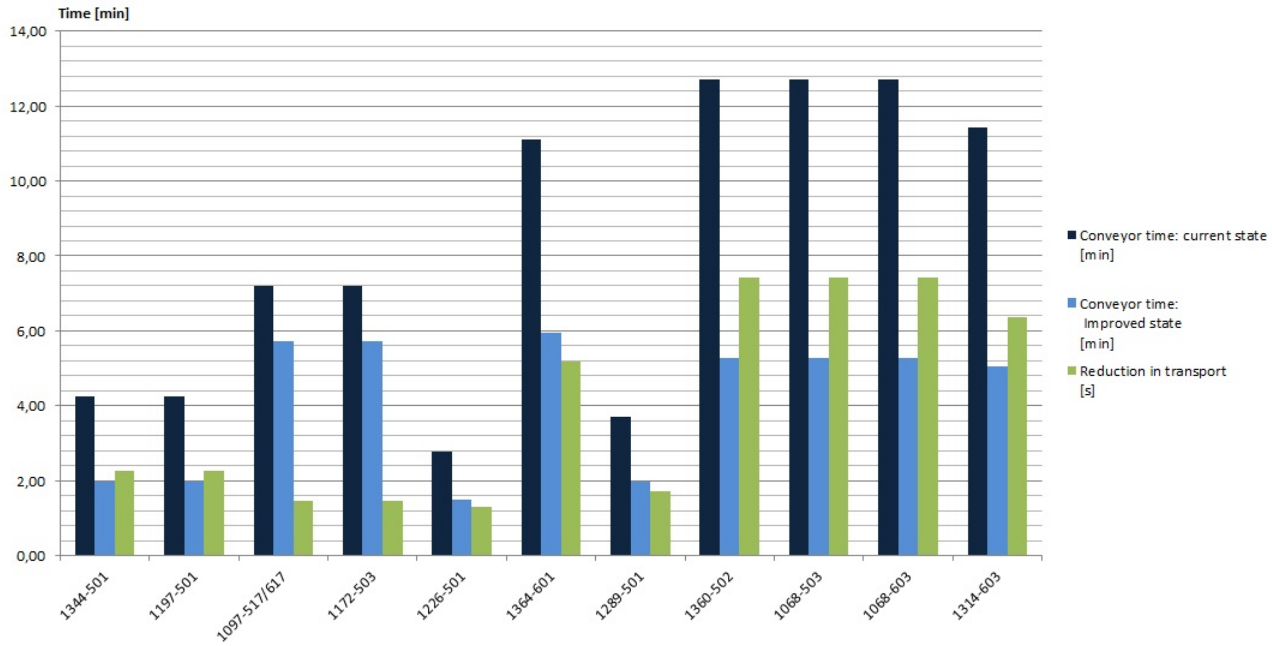


Figure 6.13: Reduction in conveyor transports

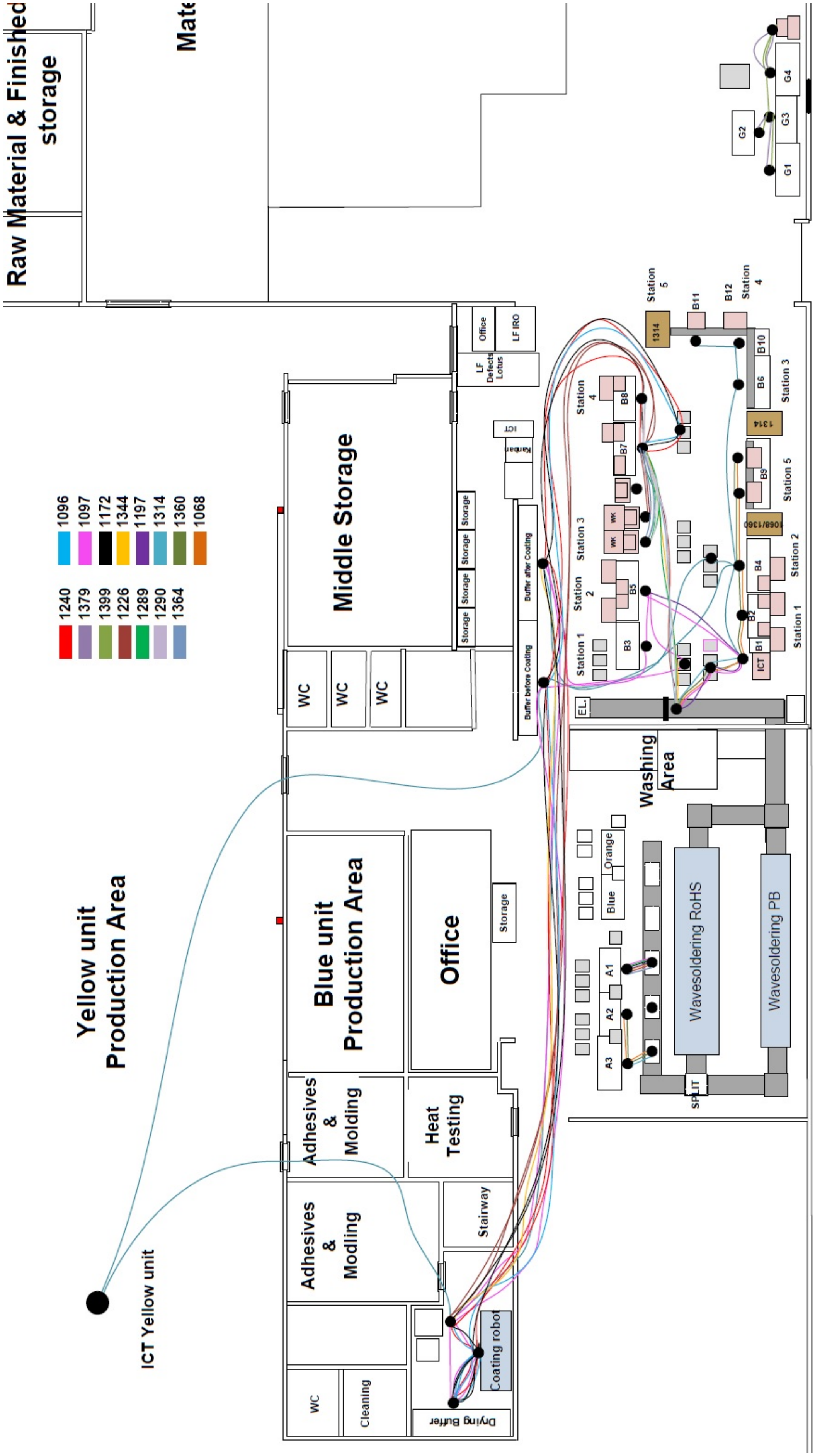


Figure 6.14: Product flow in the improved state suggested layout

6.3.1 Area Utilisation

The area utilisation was estimated trough measuring workstations, material equipment and other objects linked with the products scope and mapping them into the production floor plan. The approximated current utilised area of the products were then measured from the floor plans. This method was used for both the current state and the improved state.

The previous area used by the SPM was estimated to be 170 m^2. With the new proposed layout, the SPM would use approximately 131 m^2, which is a reduction with 23 % according to 6.1

In equations 6.1 to 6.12, the following abbreviations are used:

- CS = Current State
- IS = Improved State
- NPT = Needed Production Time
- NO = Number of Operators
- CT = Cycle Time
- PV = Product Volume
- SUT = Set Up Time

$$Reduction\ Area\ Utilisation = \frac{IS\ Area\ Utilisation - CS\ Area\ Utilisation}{CS\ Area\ Utilisation} \tag{6.1}$$

6.3.2 Productivity

Below follows first an estimation of the increase in productivity for the SPM. Then, an estimation of the total capacity increase for the improved state.

Current State Productivity
The productivity for the current state was calculated according to 6.2 .

Here, the needed production time is based on the planned production time, including distribution of operators, that the production leader was asked to do for the SPM. See table 5.11in section 5.6.

The product volumes of Week 19, the SPM, was used as the output measure.

$$CS\ Productivity = \frac{PV\ [SPM]}{CS\ NPT\ [hours]} \tag{6.2}$$

Improved State Productivity
The productivity of the Improved state was calculated in the same way as the current state productivity, see equation 6.3. The product volume is the same but the needed production time has changed. The needed production time was calculated according to equations 6.4, 6.5, 6.6, 6.7.

$$IS\ Productivity = \frac{PV\ [SPM]}{IS\ NPT\ [hours]} \tag{6.3}$$

$$IS\ NPT\ =\ Alpha\ NPT\ +\ Beta\ NPT\ +\ Gamma\ NPT \tag{6.4}$$

$$Alpha\ NPT\ =\ (Alpha\ CT\ X\ PV\ +\ Alpha\ SUT)\ X\ NO \tag{6.5}$$

$$Beta\ NPT\ =\ (Beta\ CT\ X\ PV\ +\ Beta\ SUT)\ X\ NO \tag{6.6}$$

$$Gamma\ NPT = (Gamma\ CT\ X\ PV\ +\ Beta\ SUT)\ X\ NO \tag{6.7}$$

Productivity increase
In order to analyse the increase in productivity of producing the SPM, the Current state productivity was compared to the improved state productivity according to 6.8.

$$Productivity\ increase = \frac{IS\ Productivity - CS\ Productivity}{CS\ Productivity} \tag{6.8}$$

The results of productivity calculations can be seen in table 6.4 and as can be seen, the productivity had a huge increase with 192 %. This result is considered an ideal result in productivity increase, where only the impact of Methods improvement is considered.

6.3.3 Capacity

In order to calculate the improved state capacity, the maximum product output during one week was calculated for the final assembly lines BETA and GAMMA. This was done according to equations 6.9 6.10, 6.11. This capacity was then compared to the current SPM capacity of 877 products.

$$IS\ Capacity = Beta\ Capacity + Gamma\ Capacity \tag{6.9}$$

$$Beta\ Capacity = \frac{Available\ time\ Beta}{Beta\ CT} \tag{6.10}$$

$$Gamma\ Capacity = \frac{Available\ time\ Gamma}{Gamma\ CT} \tag{6.11}$$

Table 6.4: Productivity estimations

Productivity increase based on product mix of Week 19	
Alpha line	
Alpha Cycle time [s]	81,5
Alpha Product Volume W.19	817
Alpha Number of Operators	2
Alpha Set up time [s/week]	0,4
Alpha Needed prodcution Time [h]	*37,79*
Beta line	
Beta Cycle time [s]	66,40
Beta Product Volume W.19	857
Beta Number of Operators	6
Beta Set up time [s/week]	0,6
Beta Needed prodcution Time [h]	*98,44*
Gamma line	
Gamma Cycle time [s]	2566,30
Gamma Product Volume W.19	30
Gamma Number of Operators	1
Gamma Set up time [s/week]	0,3
Gamma Needed production Time [h]	*21,69*
Productivity estimations	
Improved State Needed Production Time [h]	157,92
Improved State Productivity [products/hour labor time]	5,62
Current State Needed Production Time [h]	456,3
Current State Productivity [products/hour labor time]	1,92
Productivity increase [%]	*192*

The total Capacity increase was calculated through equation 6.12

$$Capacity\ increase = \frac{IS\ Capacity - CS\ Capacity}{CS\ Capacity} \tag{6.12}$$

The capacity of the production mix increased by 87 % with the improved state. The improved state uses resources more efficiently with lower shift time, fewer shifts and fewer operators. There is hence still room for further capacity increase, if that would be of interest in the future. See calculation in table 6.5.

Table 6.5: Capacity estimation

Capacity increase	
Beta Capacity	1594,0
Gamma Capacity	42,0
Improved State Capacity	1636,0
Current State Capacity	877,0
Capcity increase	87

7
Discussion

In this chapter, the methods, data quality and project results will be discussed. In the end, a few possible aspects for project continuation will be presented as well as some of the authors ideas for future projects.

7.1 Method

The following section aims to discuss around the chosen methods for the project and how well they contributed to meet the sought-for results.

7.1.1 Balancing method

A main factor that inflicted on the flexibility in the balancing was that balancing was made on mostly a processing step level. Each processing step can be split up in to smaller steps, groups of work tasks, but that requires more time to analyse and creating a level that is suiting for this type of production.

7.1.2 Product families

The method of forming product families might in retrospect not have been necessary since the authors in the end did not balance separate lines for each product family. Three product families were all put on one line in the balancing. However, the families did create value in helping the authors to keep a structured way of balancing SPM, since they could then be implement in the Beta line sequentially.

7.2 Data quality

Regarding the collected test equipment yields, they are quite uncertain as to how representative they are for the equipment itself and not lack of routines in production. By implementing standard cleaning routines for products arriving from the wave soldering, the test yields might have been better. This was however not part of the scope to evaluate. In the new standards time for visual inspections has been added before any boards is put to racks, this to ensure self inspection and hopefully this will increase the quality and FPY increase in test.

The collected and used yields also have a flaw in their accuracy since they vary in their design in T-log, which in turn also affect our results. For example the product, product 1314-603 has to pass five test. In T-log, the last three test, tightness test 1, tightness test 2 and final functional test are registered under the same final-functional test name. Therefore, if a product gets a fail in tightness test 1 it will still register under the final functional test FPY.

7.3 Results

The following section aims to discuss around the accuracy of the achieved results.

7.3.1 Live tests

The live tests should preferably have been performed a few more times to further verify the created standards and the compensation factors. However, it is quite time consuming for the operators to take the time to learn the standards thoroughly, when their time already is quite limited. Also, further method improvements could have been made, with the use of for example fixtures and better tools.

7.3.2 The Performance factor of MPU

In the project, only the Methods factor of Productivity was analysed (Sakamoto, 2010). However, during the two live tests it became evident that the Performance factor might have a high influence on the productivity. It could be seen that two different operators working according to the created work standard did not perform at the same speed. This was not further analysed but should be considered if further analysis is to made.

7.3.3 Creating ideal lead times

The method of using SAM as the PTS for this project has both benefits and drawbacks. The authors had only a brief experience with SAM analysis prior to this project and since SAM is a less complex PTS system then for example MTM-1, it was a suitable PTS to use since the time to learn the system was limited. MTM-1 would though have been more suiting for the work tasks themselves and would have provided as better standards. Using SAM and a compensation factor for the discrepancy is however a simple and good enough way to build a standard.

7.3.4 Balancing results

As mentioned in 7.1.1, processing steps could have been split up into smaller steps which in turn could have provided a more even balancing. Some products have much higher cycle times than others but that also has to do with the aim to utilising operators during test times in order to work more efficiently. Cycle times are high due to test equipment and in some cases, unnecessary time consuming processing steps.

In order to reduce cycle times, the test equipment must be improved and be able to perform tests quicker or being able to test more than one product at a time. Preferably the first suggestion, since the aim for Aros is to strive for Lean production and hence needs to reduce batch sizes.

Another balancing aspect that is worth discussion is the objective used. The stated aim was to minimise the number of work stations and cycle times. It was somewhat difficult to decide on when a good balance between the two had been reached, since they are contradicting. The objective was interpreted as utilising the test equipment process time as much as possible for manual work and try to reduce cycle times to the level of the most time consuming test process, for each product flow. Also, it seemed as a bad idea to reduce cycle times too much since there has not been any outspoken need for that type of increase in productivity. Also, Aros has a low volume and high mix production and therefore it did not seem relevant to decrease cycle times further.

7.3.5 Capacity and productivity increase

The Capacity increase could have been higher but it was not deemed necessary since the project aim was not to maximise capacity but it was to show a potential increase that was above 50 %.

The Productivity increase estimation were made on the assumption that the product scope was produced in weekly batches, based on the SPM, but the aim is to produce in smaller batch sizes and therefore it might have been better to present the productivity increase that displays the total increase and how it is affected by different batch sizes. Sequencing and batch sizes was not part of the project scope but in retrospect, it would have been good to focus more on.

7.4 Sustainability

As well known, sustainability rests on three pillars: Environmental, Social and Economical sustainability. As the results show, changing production layout and adopting a line-production flow increases the productivity. This clearly gives a a better economical sustainability. The fact that the result provides a more efficient production system also improves environmental sustainability. The most interesting aspect for this project however the Social sustainability.

In designing workplaces for social sustainability, there are three factors that should be considered according to (Adams and Berlin, 2014, c.2): Physical, Cognitive and Psychosocial factors.

7.4.1 Physical work environment

In this project, the physical work environment has been improved due to work rotation and shorter movement distances. The current state with one operator being responsible for producing large bathes makes for highly repetitive work tasks, which in the long run can be damaging for the body. This can be resolved with introducing work rotation. Another benefit with work rotation is that it relieves operators from long work session of performing concentration demanding work tasks in bad postures.

The physical environment of Aros has a lot of improvement potential. For example, they can work more actively with methods improvement from an ergonomic perspective and encouraging good postures etc. Since much time has been spent down on the production floor, the authors know this is an important question for the operators. Many of them has asked if the improved layout suggestion will take ergonomically issues into consideration.

7.4.2 Cognitive work environment

The cognitive environment has been improved through the flow-oriented system suggestion but it also puts more pressure on support materials as work instructions and fixtures. The production flow is more logical but the content of operator work tasks is changed drastically. One operator is no longer responsible for the entire production of one product but will be responsible for a few task of many products. The cognitive support must be in place in order to go to this new system. The type of cognitive support needed depends a lot on the planning of how to run the lines. The less mixing in product sequence and the higher batch sizes, the less cognitive support is needed since the less mixing, the easier it is to learn. However, in order to be flexible and reduce batch sizes, this should not be the aim. Instead, use work instruction that live-interact with the operator and ensures quality and takt time being met.

7.4.3 Psychosocial work environment

The suggested new way of working is highly different from the present way of working. The operators will have to let go of the full responsibility of their products and planning of how to produce them and instead work according to standards and being controlled from production management. This may cause a lack of motivation for some operators since the responsibility is what they enjoy in work. However, better planning and realistic targets is a main benefit that could be achieved with this system and this will reduce the frustration for operators and management when not being able to meet production goals. The stress in the current work environment would be decreased.

The fact that the operators will be able to work as a team would have a great impact on the psychosocial sustainability. All operators will work towards the same goal and a culture of sharing better methods would be encouraged. This requires good team building efforts and a clear view on what type of operator profile that would be needed.

7.5 Recommendations

During the project, it has become apparent that the main constraint to the efficiency of the production system is the testing equipment, both in reliability and length of process time. Aros is well aware of this but the authors however feel that it is of importance to highlight what they feel should be the main focus regarding this topic. As the authors have understood, Aros main manufacturing strategies are to provide customised high quality products which then requires their production system to be flexible. As mentioned before, their major constraint is test equipment, which at the moment are neither providing high quality or flexibility.

Their test strategy needs to be revised. The use of more universal tests, that are not product specific nor requires the product to loop back to them, would provide great benefits. For already existing testing equipment, preventive maintenance needs to be performed. As a start to this, the flow-technicians work role needs to be more clear and equipment preventive service should be prioritised.

It has also become clear during the course of the thesis that the value of continuous improvements is understood and spread across the organisation. However, many people in the staff expresses a lack of time to implement new ways of better work methods. It is therefore suggested that a new role should be created within the the production segment of Aros, namely a Lean coordinator. This role should act as link between aligning the manufacturing strategies and production as well as working with continuous improvements, which the production leaders today has no time for.

7.6 Project continuation

The results and suggestions put forward in this thesis are only showing the potential of how much productivity and capacity can be increased, by changing the production system towards a more flow orientated one and through adopting new work standards. The authors can see two clear continuation projects before any implementation could be started.

7.6.1 Buffer sizes

Due to the need of producing in batches, from the wave soldering process and the coating, products need the be put in buffers between theses processing steps. Therefore, buffer sizes need to to be set to proper levels in order to create a pull flow trough the production system.

7.6.2 Orange unit wave soldered products

To be able to create an as efficient flow as possible for products using the wave soldering machines, all products utilising them should be produced by the same production unit. Therefore the authors feel that it would be appropriate if the wave soldered products produced by Orange unit were transferred to Green units responsibility. These products then also need to have works standards constructed and balanced out on the existing production lines.

7.6.3 Potential implementation

If or when it is time for implementation of the production flow, the authors feel that the operators need to gain deeper understandings of the dynamics within the production system and how important their roles are for systems performance as a whole. It is understood that the lean game has been introduced to the white-collar workers at Aros but the authors feels that the operators would benefit of getting this opportunity as well. By playing the game, valuable insight and knowledge about the importance of process stability, shorter lead times and delivery dependability would be gained.

7.7 Future project suggestions

During the course of the thesis, the authors has been in close contact with several functions of Aros production and have identified issues related to the project but not part of the scope.They are here presented as possible future projects:

- To revise their material handling system and especially the Kanban system. The Kanban levels need to be more developed based on the speed it is used by in production. At the moment, it is not unusual that the levels are set too high, which causes both Kanban containers ending up at the workstation, taking up valuable work space. Too low Kanban levels are also existing, which causes material handling not being able to keep up with their current pace with four refill rounds per day. This in turn causes the operators to leave their workstations and fetch the the material themselves.
- Also, connected to material handling, is that we suggest that they take over some of the components preparation work from the production groups. The operators time should be spent on purely value adding activities. Since material handling currently already redistribute components from their packaging from the supplier to the Kanban containers, they should also be able to make component preparation.
- Constructing and measuring lead times is an ongoing project and Aros should not view this task as finished. Someone should be assigned the role of continuing to update the time data, as improvements are made and new products are developed. This person could preferably be assigned to also lead improvement work around the factory floor, since it is currently a gap in the way the organisation is structured.

All of above suggestions are also deemed necessary to have in place before any implementation of a production line is started.

8 Conclusion

This thesis has balanced a specified product mix of the Green production unit of Aros Electronics AB and has through that achieved a potential capacity increase of 90 %, a productivity increase of 192 % and an area reduction of 23 %. In order to balance the production mix, the authors created work standards in Avix Software that were based on SAM and Stopwatch estimations. It can be concluded that the project show that Aros has a great potential in productivity improvements and therefore this thesis provides as a good decision basis for Aros and their production development. Below follows the answers of the research questions.

Is it possible to increase Aros production capacity of a specified product mix in Green production unit by 50% if going from a process layout towards a flow oriented system? If not, which level can be reached?

Ideally, a capacity increase of 87 % is possible to reach with the method improvement made and and the new established shift hours. There is room for even more capacity if shift hours were to be revised but the authors judged that there needs to be room for improvement work in production and hence wanted to present a capacity increase that shows the great potential that exists within the unit but also convey a long term plan and the importance of working with methods improvement.

Keeping focus on both flow and resource efficiency is key in order have high productivity and capacity and this is what the balancing has shown. Also, the created work standards has given operators, management and production planning a better view on what production goals that ideally can be reached.

How much can the occupied area for the specified product mix in Green production unit be decreased when creating a flow oriented system?

The area was reduced by 23 % but it could be reduced even further if needed. It was though decided that there was no need in making the area more cramped but instead, focus was put on creating a better and more visual work environment.

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A

Appendix for Current State chapter

Table A.1: Split/Merge-capacity

SPLIT/MERGE Capacity: Stopwatch estimation	
Combinations: Type of soldering (ROHS or PB)	Time [s]
1. Same type PB-PB	35,4
2. Different types PB-RoHS	35,7
3. Same type RoHS-RoHS	36,9
4. Different types RoHS-PB	37,0

Table A.2: Process time of the wave soldering machines

Wave soldering Process time: Stopwatch estimation					
Wave soldering machine	Round				Estimated average [s]
	1	2	3	4	
PB machine	295	300	298	297	298
ROHS machine	458	449	459	453	455

Table A.3: Conveyor transports

Conveyor transports: Stopwatch estimations		
Upper level		
From	**To**	**Time [s]**
Station 1	SPLIT/MERGE	103
Station 2	SPLIT/MERGE	139
Station 3	SPLIT/MERGE	200
Station 4	SPLIT/MERGE	256
SPLIT/MERGE	PB START	97
SPLIT/MERGE	ROHS START	140
PB Delay time before start		2
ROHS Delay time before start		11
Lower level		
From	**To**	**Time [s]**
PB END	SPLIT/MERGE	143
ROHS END	SPLIT/MERGE	168
SPLIT/MERGE	Station 1	86
SPLIT/MERGE	Station 2	109
SPLIT/MERGE	Station 3	148
SPLIT/MERGE	Station 4	187

Table A.4: Coating data

Coating process data: Stopwatch estimation				
Product	**Side**	**Process time [s]**	**Cycle time [s]**	**Drying time [h]**
1240-501	Component	219	73,0	2
1096-514	Solder	190	31,7	0,5
	Component	112	18,7	2
1097-517	Solder	148	148,0	1
	Component	430	430,0	12
1172-503	Solder	189	189,0	1
	Component	356	356,0	12

Table A.5: Test units

Testing equipment units						
Product	**Variant**	**Test type**	**Test unit**	**Fixture/Jig**	**Fixture holder**	**Module**
1360	1360-502	AOI	No ID	-	-	
		ICT	8228	Data missing	-	
		Pre-Functional test	ID: 8112	ID: 8112	-	
		High-voltage test	8140	-	-	
		Final functional test	8114-2	-	-	
1068	1068-603	AOI	No ID	-	-	
		ICT	8228	Data missing	-	
		Pre-Functional test	8114-1	8114-1	-	
		High-voltage test	8140	-	-	
		Final functional test	8114-2	-	-	
	1068-503	AOI	No ID	-	-	
		ICT	8228	Data missing	-	
		Pre-Functional test	8114-1	8114-1	-	
		High-voltage test	8140	-	-	
		Final functional test	8114-2	-	-	
1399	1399-605	Final functional test	ID: 8207	No ID	-	
	1399-606	Final functional test	ID: 8207	No ID	-	
	1399-607	Final functional test	ID: 8207	No ID	-	
1379	1399-608	Final functional test	ID: 8207	No ID	-	
	1379-601	Final functional test	ID: 8207	No ID	-	
	1379-602	Final functional test	ID: 8207	No ID	-	
	1379-603	Final functional test	ID: 8207	No ID	-	
1364	1364-601	WK	ID: 8067	ID: 8184	ID 8146	ID 8183
		Display test	No ID	-	-	
		Final functional test	No ID	-	-	
1289	1289-501	WK	ID: 8067	ID: 8147	ID 8146	ID: 8145
1290	1290-501	WK	ID: 8067	ID: 8148	ID 8146	ID: 8145
	1290-601	Final functional test	No ID	-	-	
1096	1096-514	Pre-Functional test	ID: 8128	ID: 8128	-	
1097	1097-617	Pre-Functional test	ID: 8119	ID: 8113	-	
		Final functional test		No ID	-	
1344	1344-501	Final functional test	ID: 8164	ID: 8164	-	
1197	1197-501	ICT	8228	Data missing	-	
		Final functional test	No ID	No ID	-	
1314	1314-603	ICT	8228	Data missing	-	
		Pre-Functional test	ID: 9134	ID-8158	-	
		Isolation test	ID: 9140	-	-	
		Tightness test 1	ID: 8161	-	-	
		Tightness test 2	ID: 8158	-	-	
		Final functional test	ID: 9142	-	-	
1226	1226-501	WK	ID: 8096	ID:8142	-	
1172	1172-503	Pre-Functional test	ID: 8141	ID: 8135-1	-	
		Final functional test		ID: 8174	-	
1240	1240-501	Pre-Functional test	ID: 8139	ID: 8139-1	-	
		Final functional test			-	

Table A.6: Test units and Yields

Testing equipment yields				
Product	Variant & Revison No.	Test type	FPY [%]	TEY [%]
1360	1360-502-09	ICT	82,24	72,57
		Pre-Functional test	89,80	87,09
		High-voltage test	97,12	95,78
		Final Functional test	87,66	77,69
1068	1068-603-10	ICT	69,36	61,00
		Pre-Functional test	77,87	70,41
		High-voltage test	96,74	94,56
		Final Functional test	86,16	78,67
	1068-503-52	ICT	64,06	56,59
		Pre-Functional test	78,45	63,10
		High-voltage test	96,92	93,54
		Final Functional test	81,40	64,02
1399	1399-605-07	Final Functional test	76,36	66,67
	1399-606-05	Final Functional test	53,85	50,63
	1399-607-04	Final Functional test	75,00	71,43
	1399-608-02	Final Functional test	81,25	80,95
1379	1379-601-09	Final Functional test	82,41	65,27
	1379-602-03	Final Functional test	77,29	71,25
	1379-603-03	Final Functional test	81,48	66,67
1364	1364-501-08	WK	66,29	52,58
1289	1289-501-14	WK	64,70	49,78
1290	1290-501-09	WK	66,01	53,88
	1290-601-19	Final Functional test	91,44	91,67
1172	1172-503-01	Pre-Functional test	77,66	65,43
		Final Functional test	88,95	83,10
1096	1096-514-01	Pre-Functional test	82,32	75,50
1097	1097-517-01	ICT	53,73	68,29
		Pre-Functional test	84,40	75,12
	1097-617-01	Final Functional test	69,50	59,78
1344	1344-501-14	Final Functional test	87,71	81,70
1197	1197-501-17	ICT	90,71	88,18
		Final Functional test	75,27	66,69
1226	1226-501-12	Final Functional test	65,40	58,22
1240	1240-501-17	Final Functional test	55,38	60,78
1314	1314-603-05	ICT	29,38	39,96
		Pre-Functional test	54.74	48,72
		Final Functional test	83,87	78,33

Table A.7: ICT Capacity data and estimation

Green unit ICT Capacity: Calculated							
Product	Product volume Week 19	Process time [s]	ICT First pass yield [%]	First pass yield average [%]	Manual handling: Before ICT [s]	Manual handling: After ICT [s]	Set up between new batch [s]
1197-501	100	60.8	90,71	65	30	10	180
1360-502	177	74.1	82,24				
1068-503	60	121.2	64,06				
1068-603	59	99.8	69,36				
1314-603	25	69	29,38				
1097-617	30	76.6	59,78				
1173-501	42	63.25	71,76				
1175-501	600	61.6	47,62				
1000-502	12	54.8	71,54				

B

Appendix for Analysis chapter

Table B.1: Ideal lead times constructed in Avix based on current state layouts transports

Ideal lead times based on current state layout											
Article:	Boards/ panel	PB/RoHS	THM Manual labour [s]	Other Manual labour [s]	Total: Manual labour [s]	Total: Test times [s]	Conveyor time: current state [s]	Process: Wave soldering [s]	Process: Coating [s]	Total: Drying time [s]	Total ideal lead time [s]
1344-501	3,0	RoHS	118,4	115,3	233,7	137,0	254,0	23,3			648,0
1197-501	3,0	RoHS	122,4	86,5	208,9	150,0	254,0	23,3			636,2
1097-517/617	1,0	PB	104,3	1432,6	1536,9	331,0	431,0	38,0	578,0	54000,0	56914,9
1096-514	6,0	PB		127,3	127,3	92,0			50,3	2700,0	2969,7
1172-503	1,0	PB	95,5	842,0	937,5	310,0	431,0	38,0	545,0	54000,0	56261,5
1240-501	3,0	PB		940,3	940,3	326,6			73,0	4800,0	6139,9
1379-601	1,0	RoHS		1447,2	1447,2	235,0					1682,2
1379-602	1,0	RoHS		1447,2	1447,2	220,0					1667,2
1379-603	1,0	RoHS		1447,2	1447,2	222,0					1669,2
1399-605	1,0	RoHS		2441,0	2441,0	607,0					3048,0
1399-606	1,0	RoHS		2441,0	2441,0	599,0					3040,0
1399-607	1,0	RoHS		1781,5	1781,5	318,0					2099,5
1399-608	1,0	RoHS		2441,0	2441,0	639,0					3080,0
1226-501	4,0	RoHS	53,5	18,4	71,9	109,5	166,8	17,5			365,7
1364-601	1,0	RoHS	96,7	1479,2	1575,9	810,0	667,0	70,0			3122,9
1290-501/601	2,0	RoHS	104,1	388,7	492,8	99,3		35,0			627,1
1289-501	3,0	RoHS	9,5	482,2	491,7	341,0	222,3	23,3			1078,4
1360-502	1,0	RoHS	390,1	438,4	828,5	409,0	762,0	70,0			2069,5
1068-503	1,0	RoHS	399,3	378,8	778,1	482,0	762,0	70,0			2092,1
1068-603	1,0	RoHS	389,3	495,1	884,4	515,0	762,0	70,0			2231,4
1314-603	1,0	PB	178,6	1773,1	1951,7	448,0	685,0	38,0			3122,7

Table B.2: Process times used in Avix

Testing equipment process times used in Avix: Stopwatch Estimated/Based on Logged data/Mix of both *Colored marking = Used time in AviX									
Product	Variant	Testtype	Estimated		Logged		Mixed		Manual handling time
			Time [s]	Sample size	Time [s]	Sample size	Time [s]	Sample size	Time [s] or simple check
1360	1360-502	AOI	3	3					
		ICT	24,4	3	27	5			
		Pre-Functional test			124	5			
		High-voltage test	61,7	3	56	4			
		Final functional test	199	3	203	5			Check
1068	1068-603	AOI	3	3					
		ICT	35	1	44	5			
		Pre-Functional test	208,7	3	208	5			
		High-voltage test			57	5			
		Final functional test	203	3	397	5			Check
	1068-503	AOI	3	3					
		ICT	37	1	58	5			
		Pre-Functional test	158,7	3	158	5			
		High-voltage test	58	1	56	5			
		Final functional test	207	3	756	5			Check
1399	1399-605	Final functional test			607	5			Check
	1399-606	Final functional test	631,5	2	599	5			Check
	1399-607	Final functional test			318	5			Check
	1399-608	Final functional test			639	5			Check
1379	1379-601	Final functional test	235	1	235	5			Check
	1379-602	Final functional test			220	5			Check
	1379-603	Final functional test			222	5			Check
1364	1364-601	WK	600	1	598	1			Check
		Display test	71	1					Check
		Final functional test	141	2					Check
1289	1289-501	WK	341,2	3	240	5			74
1290	1290-501	WK	45	3	42,2	5			
	1290-601	Final functional test	54,3	1					54,3
1096	1096-514	Pre-Functional test	84,4	7	102	5	92	12	
1097	1097-617	ICT			25	5			
		Pre-Functional test	227,6	5	221	5	224	10	
		Final functional test	83,2	5	96,8	6	82	11	
1344	1344-501	Final functional test	110	5	164	5	137	10	Check
1197	1197-501	ICT			19	5			
		Final functional test	130	5	133	5	131	10	Check
1314	1314-603	ICT			17	5			
		Pre-Functional test	162,8	4	151	6	156	10	
		Isolation test	12	2					
		Tightness test 1	20	2					
		Tightness test 2	123,2	2					
		Final functional test	120	4	492	9			
1226	1226-501	WK	219	2	111				
1172	1172-503	Pre-Functional test	304,8	5	311	7	308	12	
		Final functional test	1,4	5	2,4	5	2	10	
1240	1240-501	Pre-Functional test	258,4	1	293	5			Check
		Final functional test	68,2	1	130	5			42

C

Appendix for Solutions chapter

Table C.1: Estimated time data for conveyor transports in the Improved state

Conveyor transports Improved state		
From	**To**	**Time [s]**
Station A3	SPLIT/MERGE 1	143,00
Station A2	SPLIT/MERGE 1	123,00
Station A1	SPLIT/MERGE 1	103,0
SPLIT/MERGE 1	PB START	140,0
SPLIT/MERGE 1	ROHS START	97,0
PB Delay time before start		2,0
ROHS Delay time before start		11,0
PB END	SPLIT/MERGE 2	18,09
ROHS END	SPLIT/MERGE 2	64,26
SPLIT/MERGE 2	Beta line station 1	40,70