Abstract

This thesis was conducted at Enics manufacturing unit in Västerås. This site employs 360 people out of a total of 2400 globally. The site produces electronics and is specialised toward low volumes and spare parts.

The site has problems with high inventory levels, long lead times and less than preferred service level towards customers. This is the reason for the project which will investigate if it possible to implement a cell configuration with one piece flow for a part of the production process. The difficulties consist of the high variation in products and process flows which makes planning and grouping of products difficult.

To aid this project a Six Sigma methodology called DMAIC (Define-Measure-Analyse-Improve-Control) was used. Tools and principles from Lean manufacturing was also used and discussed. Data from the production has also been collected by the author.

As a start a suggested product family was presented by Enics. Process mapping was done for all products by using process maps, spaghetti diagrams and value stream mapping. The initial product family had to be dismissed and a new product family was chosen by analysing process flows and demand for all products. This second product family was then analysed in order to decide if a cell configuration was possible.

In the end the project concludes that a cell configuration with one piece flow is feasible and it is partly implemented. A number of layout suggestions are made for future development. A discussion regarding the problems the company are facing follows before the author concludes that the company should continue implementing the fundamental strategies from lean manufacturing despite being a smaller company. Much of the principles are applicable and possible despite the high product variation and lack of resources in the company.

Abbreviations

EMS	Electronics Manufacturing Service
CTQ	Critical To Quality
DFSS	Design For Six Sigma
DMADV	Define Measure Analyse Design Verify
DMAIC	Define Measure Analyse Improve Control
DPMO	Defects Per Million Opportunities
FIFO	First In First Out
HVLV	High Variety Low Volume
ICT	In Circuit Test
IMVP	International Motor Vehicle Program
IPC	Association Connecting Electronics Industries, previously Institute for Printed Circuits
KPI	Key Performance Indicator
MTO	Make To Order
PCBA	Printed Circuit Board Assembly
ROHS	Reduction Of Hazardous Substances Directive
SIPOC	Supplier Input Process Output Customer
SME	Small to Medium sized Enterprises
SMED	Single Minute Exchange of Die
SUF	Single Unit Flow
TOC	Theory Of Constraints
TPM	Total Productive Maintenance
VSM	Value Stream Map

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1 Introduction

This chapter will give the reader an overview of what the entire thesis contains. The chapter consists of background, company presentation, problem discussion, purpose, delimitations and outline. After reading this chapter the reader should have an understanding of what the thesis is about and how it is conducted.

1.1 Background

Business management strategies has been around for a long time, at least from the beginning of the last century and much of what is referred to as tools are originally common sense employed in a scientifically way.

Six Sigma is a quality orientated improvement method originally derived by Motorola in 1981. More specifically it was an engineer called William Smith who is known as the father of Six Sigma, although many more have been working on the problems with reducing variability and improving quality[1] (essentials of lean six sigma). Six Sigma focuses on identifying causes for defects and removing them, always with the customer in focus. The underlying assumption is that every process can be described with a statistical distribution curve which can be used to measure the variability and behavior of the process.

Lean manufacturing is another production practice that has been developed from the Toyota Production System in the 1960s which in turn has origins from the beginning of the 20th century. Lean manufacturing differs between value adding activities and waste, everything not considered to add value to the product is considered to be waste. Another viewpoint is that value added is everything the customer is prepared to pay for, all the rest is waste. Fundamental approaches in Lean is to remove or at least minimize all stocks such as inventories and finished goods, this forces everyone involved to do their best in order to avoid costly mistakes as they will incur complete stops in production. Since there is no room for errors all problems are laid bare and can be dealt with.

One approach in both Six Sigma and Lean is to reduce variability in processes, to increase flow and smoothness. Recently these two manufacturing philosophies have been combined into Lean Six Sigma where tools from both Lean and Six Sigma are used together. This thesis will use tools from Lean Six Sigma in the empirical part of the study. A

[1] Taghizadegan S. 2006

deeper and more thorough presentation of these business management strategies can be found in chapter 5.

1.2 Company presentation

Enics is an EMS (Electronics Manufacturing Services) company focused towards the global industry and medical business with more than 40 years of experience in Industrial Electronics[2]. The total numbers of employees are in the range of 2400 and annual sales in 2009 reached €271 Million. There are 7 manufacturing plants in Asia and Europe with headquarters in Zürich, Switzerland. Two Enics' plants are located in Sweden, one in Malmö and one in Västerås. Enics business unit in Västerås is housed in a building of approximately 9000 square meters and has 360 employees. Of these 260 are blue collar workers working daytime, 2 shifts and night shift production. The factory produces a wide range of PCBA products from prototyping to spare parts production and therefore the product mix is very high, ranging from low to medium volumes. Currently the factory is responsible for more than 4500 different products. This high variety requires a very flexible production system and a deep knowledge of electronics since many products are spare parts from past decades. The services offered by Enics include engineering services, manufacturing, life extension, after sales, supply chain management and customer relationship management. The manufacturing part in turn consists of board assembly (both ROHS and non ROHS), box build assembly, low volumes production and prototyping. Typical processes used for PCBAs is surface mount technology, primary and or secondary sided, automated or manual through hole technology with selective or wave soldering, testing on board level; either through in circuit testing or with flying probe testing. In some cases PCBAs are coated with conformal coating and usually PCBAs are high voltage tested for any shortages. Most PCBAs are then assembled in some kind of box build solution with following testing such as burn in testing and functional testing before being packed and shipped to customers. The high amount of testing is usually a customer demand because of the type of products being manufactured at this site, the majority being some kind of safety or monitoring solution in nuclear power plants, electrical grids, railway control systems or onboard train safety systems.

[2] Enics company presentation, www.enics.com

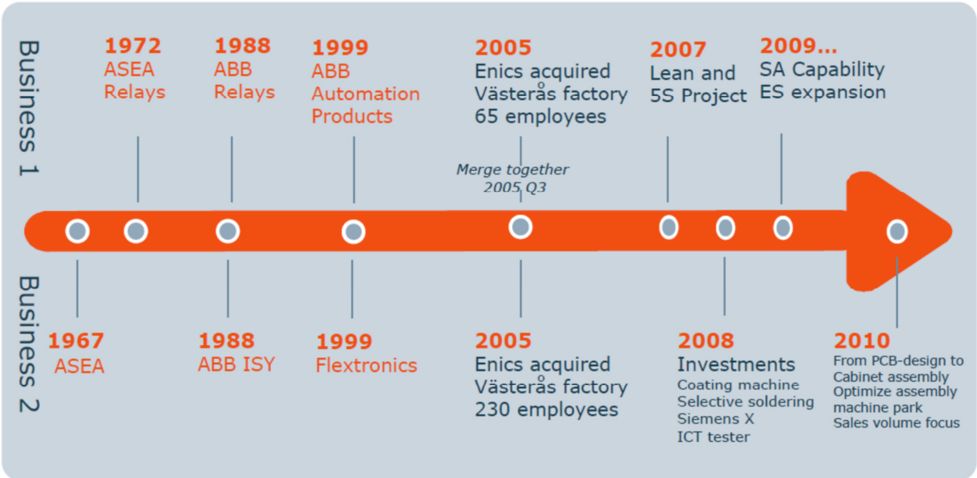

Figure 1 Enics Västerås history[3]

The production started in 2005 after two production units was acquired by Enics from ABB and Flextronics and merged in Q3 2005. The two different parts were founded in 1972 and 1967 respectively by ASEA. All of which are part of Enics idea to offer services over the whole life cycle, from developing and prototyping to maintenance and repair. The services offered in Västerås business unit cover the beginning and end of the life cycle management. The strategy is visualized in the following figure:

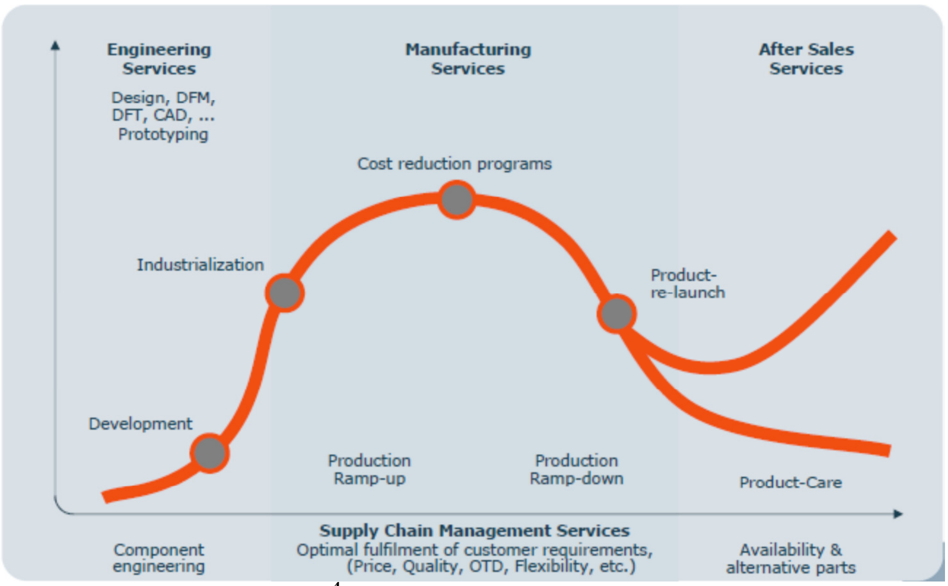

Figure 2 Enics life cycle strategy[4]

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[3] Enics company presentation, www.enics.com
[4] Enics company presentation, www.enics.com

1.3 Problem discussion

Manufacturing consisting of a very large product mix requires a very flexible production. Usually it is realised in a functional configuration with batch production; this is the case in the Enics business unit in Västerås. One difficult issue in high mix production is the need for is frequent changeover. Quite often this result in high inventories in the form of queues in between processes. One way of addressing this problem is with reduced changeover times and smaller batch sizes. In lean production the optimal way of producing is by using one piece flow, which is possible with mixed production but much harder to do and possibly limited by high variation in the process flows. Some companies have approached the problem by starting a lean six sigma initiative to reduce quality problems and to create smoother manufacturing with less waste. This, however, is not easy in a smaller company with high product diversification and low to medium volumes, the framework was developed for and by companies with much larger production and fewer products. How a lean six sigma framework is applicable to smaller companies with higher product diversification will be discussed in chapter 5. Today Enics have problems in their production with high inventories, lots of work in process, long lead times and quality issues. In order to receive guidelines and assistance in dealing with these problems lean six sigma has been chosen and tools from this framework will be used within the company.

1.4 Purpose

A one piece flow cell would solve many of the problems with lead times, work in process, inventories and quality and has been chosen as the preferred solution, but implementing a one piece flow cell may not be possible because the high product diversification may cause long setup times, low utilization or lowered process efficiency. Also, there may not be enough products with similar routes. Therefore this projects task is to investigate how to choose products, design a work cell and implement the new work cell into the organization. If it is deemed impossible to create a one piece flow work cell the task will be to suggest alternative solutions to the problems at hand. The project will be finished off by suggesting further possible projects and improvement ideas. In order to structure the project the six sigma methodology DMAIC; Define, Measure, Analyse, Improve and Control has been chosen, apart from this several lean tools will be used in the improvement. If time is available, an actual change of the production could be part of this project.

1.5 Delimitations

Certain delimitations has been done in agreement with the supervisor and Enics in order to match the extents of the work to the limited timeframe. Of the different phases the implementation and control phase will be done depending on available time. The processes included in the thesis start after surface mounting and end after surface coating; this means they include manual assembly, soldering, visual inspection, PCB depaneling, in-circuit testing (ICT), washing and conformal coating. Excluded processes are surface mounting, further testing and box build.

1.6 Outline of thesis – disposition

The thesis starts with an introduction to give the reader an overview of what the thesis contains. Here after the methodology is presented with a discussion about research problems such as which approach to use and issues regarding this approach. In chapter 5 the theoretical framework is presented with some of the relevant theory. These first three chapters contain the theoretical part of the thesis, the following chapters contain the more empirical part with the DMAIC-method used in the project and each part has its own chapter. Following the empirical part is a chapter with conclusions and a discussion.

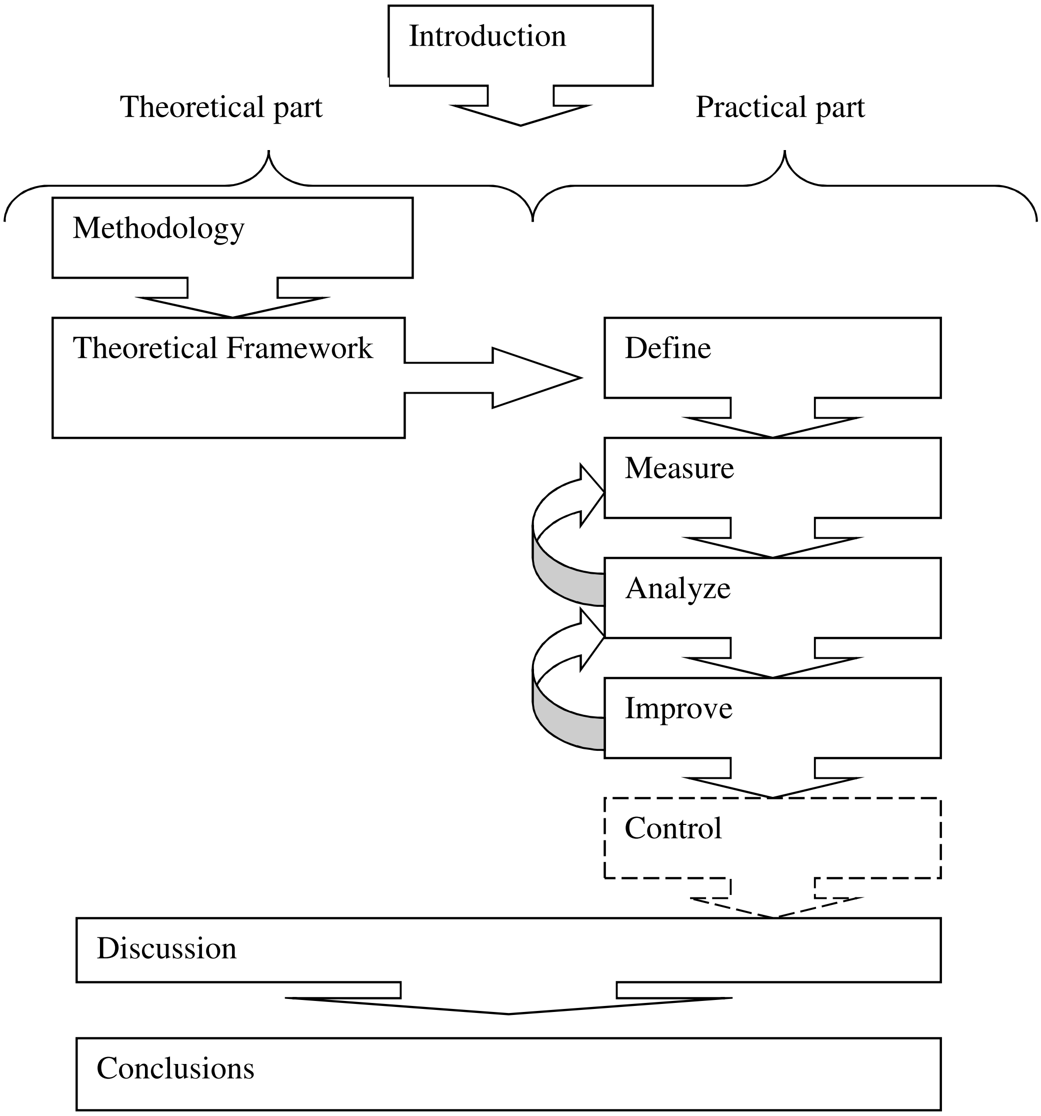

Figure 3 Outline of thesis

4 Methodology

In this chapter the methodology used in this thesis will be described and different approaches and methods will be discussed. The general tools for the project will also be introduced.

4.1 Approach / research strategy

In Höst[5] four different types of research approaches are discussed; case study, survey, experiment and action research.

A case study is meant to give an in depth description of a phenomenon, affecting what is described as little as possible. Common techniques used in a case study are interviews, observations and analysis of archives.

Surveys collect and present information in an effort to describe a phenomenon, information is gathered from a sample population and from the result of this information conclusions regarding the whole population are made. How to select the sample is an important question in this type of research and the data gathered can be analysed statistically.

Experiments are a way to find cause and effect for a phenomenon, experiments can also compare different applications. In an experiment factors are isolated and compared, and from these the conclusions can be made. Volunteers can be used in experiments but the selection of a sample of volunteers is important to avoid bias.

Action research is used when improvements are wanted at the same time as understanding and investigation. Action research according to Höst[5] is done in consecutive steps starting with observations to identify the problem at hand. The next step is to analyse the observations and come up with solutions and the final step is to evaluate the solutions.

Another related approach used in quality improvement is presented in Bergman and Klefsjö[6] called Shewart cycle and consists of the steps plan, do, study and learn. In this master thesis an experimental research approach called DMAIC from Six Sigma will be used consisting of the five steps Define, Measure, Analyse, Improve and Control. This choice is made because the scope from Enics side is not just to describe or investigate but to actually change their production process and experimental research methodology does just that. In combination with this experimental research

[5] Höst et al. 2006
[6] Bergman and Klefsjö 2002

a literature study of the related theory is performed in order to provide a good theoretical foundation for conclusions and discussion later in the thesis.

4.2 Research purpose

Exploratory research is a type of research done when there is no predefined theory to start with; exploratory research is often very fundamental and often answers the question whether there is a problem to investigate further. Descriptive research is also known as statistical research as it uses averages and numbers to describe a phenomenon. It is however limited as it does not explain the causes behind the phenomenon despite being accurate in numbers. Explanatory research looks for cause and effect as well as explanations to how something works or is performed while problem solving research has the purpose of solving a specific problem.[7] These are some of the different purposes a research project can have. The purpose of this thesis is problem solving but all elements are present to some extent, descriptive elements will be found in the definition and measure phases and explanatory elements can be found in the analyse phase. Exploratory elements could be found in the theoretical chapter since discussion regarding small enterprises and lean manufacturing are rather uncommon.

4.3 Inductive or deductive research

Inductive or deductive approaches stem from two completely different philosophical branches, rationalism and empiricism. Rationalism claims that it is possible to come to a conclusion only from using reason and logic while empiricism claims that it is only possible to make a valid claim if it is built on experience and evidence. Therefore inductive research starts with gathering of evidence and observations; these are then analysed in order to find patterns to form hypotheses on. These hypotheses are turned into theory and results. Deductive research on the other hand starts with theory and hypotheses which are then examined with observations and evidence. In the end a hypothesis is confirmed or dismissed. This thesis is mainly deductive; it starts out with an idea of what might be possible then data is gathered to be analysed to confirm or dismiss this idea. If the original theory turns out not to be true an alternate theory is formed based on the data analysed and later tested. This iterative approach is mainly deductive but could be said to have inductive elements if an alternative hypothesis is found based on the

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[7] Höst et al. 2006

observations made. An iterative approach is supported in the DMAIC methodology both by returning to a previous step or by repeating the whole process once a solution is implemented in order to find further improvements. The reason DMAIC has been chosen as the tool for this project is the straightforward methodology that goes well with experimental research and the fact that knowledge of this methodology exists within the company. Experimental research in turn fits the scope of the thesis; to come to a conclusion about and hopefully implement a solution to some of the problems within the production.

4.4 Data gathering

When gathering data it is important to reflect on what the data is supposed to measure and how to make sure the data is accurately describing the phenomenon. There are two main types of data collection methods, qualitative and quantitative. Data can also be of two types, primary and secondary, secondary data is data not directly related to the study while primary data is. An example of secondary data is literature. Primary data will be collected within Enics in the form of cycle times, work in process and setup time among other things while secondary data is used for the theoretical chapter.

4.5 Qualitative or quantitative research

Qualitative research is a method of inquiry used when an in-depth understanding is needed; it is usually used in the social sciences. Qualitative data is non-numerical and explanation based. Other terms for qualitative research are naturalistic, humanistic and interpretative. Quantitative research on the other hand is systematic empirical investigation of phenomena that have quantitative properties. The data in quantitative research is numbers, mathematical models, expressions and graphs. Qualitative data can often be used in combination with quantitative data in order to verify that the quantitative data is measuring what was intended to be measured. Quantitative research is often performed in three steps[8]; a first step involving reviewing literature to develop a theoretical foundation on which the research will be based, a second step in which a formal theory is developed and in the third step data is collected to verify or dismiss the previously developed theory, this is essentially a deductive research approach. This thesis will mainly be quantitative as large amounts of data in numerical form will be collected during the production but it will also be qualitative in nature since investigation is also performed through interviews

[8] Golicic et al. 2005

with people in the production. It is important to combine methods of research in order to reach a more balanced approach (Figure 4 Illustration of a balanced approach from Golicic et al.) and in order not to delimit the scope of the research.[9]

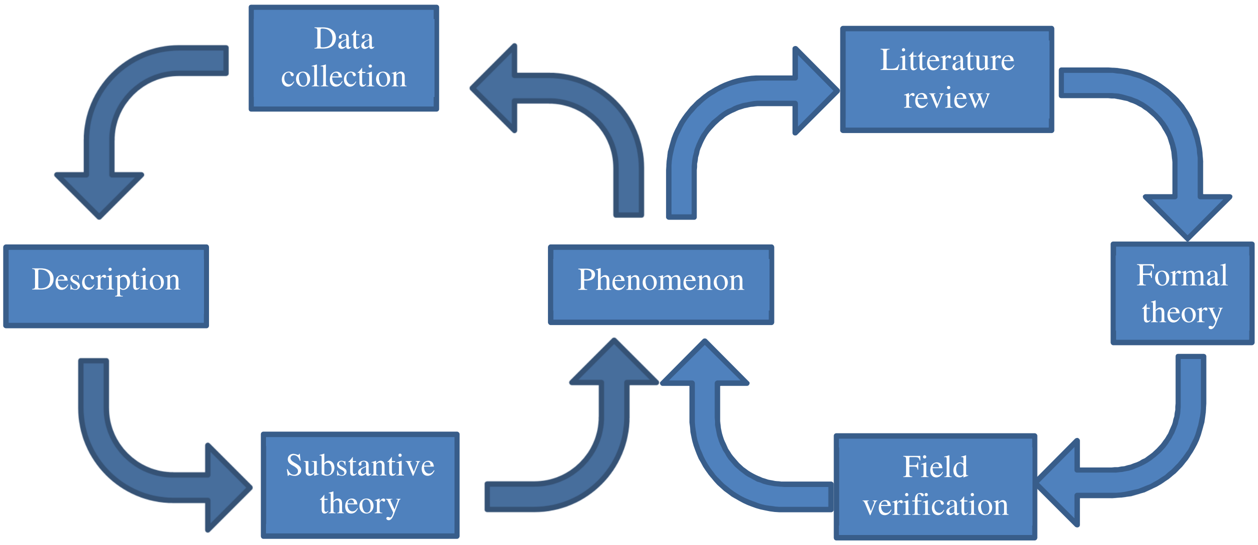

Figure 4 Illustration of a balanced approach from Golicic et al.

4.5.1 Data gathering in this project

There are multiple sources for data; there is a time registration system, internal standard times used for planning and quoting and also actual timing of production with a stopwatch. All of these different sources will be used depending on what will be measured; the reliability of the sources is continually evaluated to ensure validity. Apart from this data a literature review is performed and the sources were carefully chosen from article search engines such as ELIN (Electronic Library Information Navigator) from Lund University.

[9] Golicic et al. 2005

4.6 Reliability and validity

The validity of research is how relevant the measured facts are for the research. In order to ensure validity there are a few things to consider. Firstly the data collection technique has to give us the information we are interested in, this can be verified by asking people with insight to check the face validity. Secondly the criterion validity has to be verified to ensure that the result matches that of similar measures. This is checked through multiple different sources of data in this thesis. Thirdly, construct validity is whether related measures support our conclusions. Fourthly there is a communicative validity which is the researcher's ability to communicate the methodologies used and conclusions made. Lastly there is a pragmatic validity which is whether the knowledge is useful or not. Reliability of research is how reliable the information are, how accurate our measures are. In order to ensure reliability there are a few things to consider, one is whether the measurements are free from bias or not. Another thing to consider is whether the measurements are time independent or not, measurements made at different points in time should not differ. Both validity and reliability is important and it is important to remember that a high reliability does not guarantee a high validity and a high validity requires a high reliability. The reliability and validity of clocked times is good since the data can be confirmed while the measuring is done. Clocked time is also statistically verified for reliability by checking variance and not just looking at mean values. Other sources of data such as time taken from the internal time collection system and time in the production system cannot be verified and therefore they cannot be used to make conclusions, however, they can be used in order to filter products for closer analysing such as grouping. This will be done in this thesis.

5 Theoretical framework

This chapter will lay the theoretical foundation for the practical part of the thesis; it will go through the principles of lean production and six sigma and the combination of the two. Six sigma and lean implementation in small to medium sized enterprises is also discussed and in the end some critique of these toolsets are brought up.

5.1 Lean

Many different names have been used to describe what is sometimes referred to as Lean Production; other examples are Just-In-Time and Toyota Production System. Depending on which author is read different definitions are found. In Bonavia & Marin 2006[10] several different opinions are found and agreement between three so called bundles are found; JIT, TQM and TPM and also support for a fourth bundle, human resource management, HRM. As to what tools these bundles in turn consist of there is also disagreement and different versions exist between different authors, an example of the different existing views can be seen in Table 1.

Bundle	Practice	Authors
HRM	Multifunctional employees/cross training/task rotation	Cua *et al.* (2001), Forza (1996), Fullerton and McWatters (2001), Gupta and Brennan(1995), Jackson and Dyer(1998), James-Moore and Gibbons(1997), Karlsson and Ahlström(1996), Katayama and Bennet(1996), Lee(1996), Marin and Delgado(2000), Martinez Sánchez et al. (2001), Prado Prado (2002), Shah and Ward (2003), White *et al.* (1999) and Womack *et al.* (1990)
HRM/TQM	Group suggestions programmes (quality circles,…)	Cua *et al.* (2001), Forza (1996), Fullerton and McWatters (2001), Jackson and Dyer(1998), Karlsson and Ahlström(1996), Lee(1996), Marin and Delgado(2000), Martinez Sánchez *et al.* (2001), Prado Prado (2002), Sakakibara *et al.* (1997), Shah and Ward (2003) and White *et al.* (1999)
HRM/TQM/TPM	Visual factory /information and feedback to employees/industrial housekeeping	Cua *et al.* (2001), Jackson and Dyer(1998), Karlsson and Ahlström(1996) and Prado Prado (2002)

[10] Bonavia and Marin 2006

JIT	Group technology/cellular manufacturing/functional equipment layout	Cua *et al.* (2001), Forza (1996), Fullerton and McWatters (2001), Gupta and Brennan(1995), Jackson and Dyer(1998), Lee(1996), Marin and Delgado(2000), Martinez Sánchez et al. (2001), Prado Prado (2002), Sakakibara *et al.* (1997), Shah and Ward (2003) and White *et al.* (1999)
JIT	Reduction of set-up time	Cua *et al.* (2001), Flynn and Sakakibara (1995), Forza (1996), Fullerton and McWatters (2001), Gupta and Brennan(1995), Jackson and Dyer(1998), James-Moore and Gibbons(1997), Karlsson and Ahlström(1996), Lee(1996), Marin and Delgado(2000), Martinez Sánchez et al. (2001), Prado Prado (2002), Sakakibara *et al.* (1997), Shah and Ward (2003), White *et al.* (1999) and Womack *et al*. (1990)
JIT	Level production/uniform workload	Flynn and Sakakibara (1995), Fullerton and McWatters (2001), Gupta and Brennan(1995), Jackson and Dyer(1998), James-Moore and Gibbons(1997), Lee(1996), Marin and Delgado(2000), Martinez Sánchez et al. (2001), Prado Prado (2002), Sakakibara *et al.* (1997), White *et al.* (1999) and Womack *et al*. (1990)
JIT	Pull system/Kanban	Cua *et al.* (2001), Flynn and Sakakibara (1995), Fullerton and McWatters (2001), Gupta and Brennan(1995), Jackson and Dyer(1998), Karlsson and Ahlström(1996), Lee(1996), Marin and Delgado(2000), Martinez Sánchez et al. (2001), Prado Prado (2002), Sakakibara *et al.* (1997), Shah and Ward (2003) and White *et al.* (1999)
TPM	Total productive maintenance	Cua *et al.* (2001),), Forza (1996), Fullerton and McWatters (2001), Gupta and Brennan(1995), Jackson and Dyer(1998), James-Moore and Gibbons(1997), Lee(1996), Marin and Delgado(2000), Martinez Sánchez et al. (2001), Sakakibara *et al.* (1997), Shah and Ward (2003), White *et al.* (1999) and White and Prybutok (2001)
TQM	Quality controls/statistical quality control methods (SPC)	Flynn and Sakakibara (1995), Forza (1996), Fullerton and McWatters (2001), James-Moore and Gibbons(1997), Karlsson and Ahlström(1996), Lee(1996), Marin and Delgado(2000), Martinez Sánchez et al. (2001), Prado Prado (2002), Shah and Ward (2003) and White *et al.* (1999)
TQM/JIT	Standardisation of operations/documentation of production procedures	Appelbaum and Batt (1994), Forza (1996), Jackson and Dyer(1998), Niepce and Mollerman (1996) and Prado Prado (2002)

Table 1 A compilation of authors' different views of lean production.[11]

[11] Bonavia and Marin 2006

Regardless of exactly which so called bundle is chosen there is a long discussion in ‘The machine that changed the world’ regarding the findings of IMVP (International Motor Vehicle Program)[12]. What distinguishes Japanese auto manufacturers from the rest are not labelled as sets of tools in this book, instead the 20 year long process that the car manufacturers went through is described. Lean is not characterized best with a list of tools, it is best described by a process that has emerged over time and is very hard to implement over a short time period. Lean is more than a system; it is a philosophy and a culture that runs through an entire company. The listing of tools is an attempt to transfer techniques in a way which is easy to understand and have its benefits but also limitations.
The different elements of lean production as described in[13] are:

5.1.1 Factory design

Womack and Jones discusses the differences between large auto manufacturers factory layouts, lean producers tend to have smaller factories, yet a higher productivity. Inventories are much smaller, measured on an hourly basis instead of daily. The reasons for higher productivity are discussed and the findings according to Womack and Jones are that a certain level of automation is beneficial but one of the main reasons is manufacturability. Other reasons are the multi skilled workers divided into teams as opposed to workers of low skill supported by specialists. The lack of space in the factory is a consequence of the lack of inventories cluttering the floor space and just in time supply of materials.

5.1.2 Product design

Lean product design and development is compared to mass production product design and development and the major differences are the roles and power given to the leader of the project. Also a lean product development starts with many people involved and also integrates all the different aspect of the company from the start in an attempt to reduce mistakes and later revisions.

5.1.3 Supply chain

The supply chain of a lean enterprise consists of fewer suppliers than traditionally and the suppliers are given more responsibilities such as product development and process development. The gains from optimizing the production over time are split between supplier and assembler and

[12] Womack et al. 1990
[13] Womack et al. 1990

information is shared openly. The relationship between assembler and suppliers are supposed to channel the effort of both parties toward mutually beneficial goals.

5.1.4 Worker environment in lean

Worker environment has been criticised in lean because there are opinions that lean methods pushes workers continually in a way that puts a lot of stress on the individual worker. Lean advocates will point out that workers in a lean environment has much higher possibilities to improve their work place and much more responsibilities, things that enables a more rewarding as well as challenging career.

5.2 Principles

5.2.1 Value

Creating value for the customer is the first step; this is the most important task for a company. Value is what the customer is prepared to pay for; this is the definition that should be used, to specify value correctly is crucial. Where the value is created is irrelevant, the creation is what matters.

5.2.2 Value flow

To identify where value is created is important, this can be done by dividing activities into value adding, non-value adding but necessary and non-value adding and unnecessary. A way of doing this is by setting up value stream maps for products; this will be done later in the practical part of the thesis.

5.2.3 Flow

To create a continuous flow through processes focused on the product is a goal in lean. In more traditional manufacturing batches are used and the majority of time is spent waiting in between processes, something that creates large inventories and other problems. In lean production the goal is to have one piece flow throughout the production.

5.2.4 Pull

In traditional manufacturing push productions is used, in lean production the preferred way is pull production. In pull production manufacturing is done on signals from downstream production when inventories are running low and in the end the signal comes from the customer itself. This leads to right products made at the right time and reduced waste from overproduction.

5.2.5 Perfection

The culture of a company is very important and in lean the goal is to create a mindset among co-workers to strive towards perfection, to never be satisfied and always try to improve. This is essential to maintain a competitive edge and not lag behind competition.

5.2.6 Muda

Lean production stipulates seven different types of wastes, all of which the goal is to eliminate (or at least reduce). This is a central part of lean production.
Overproduction is considered the worst waste since it could create or hide more of the other wastes. Overproduction is simply producing more than what is required from customers or do *earlier* than needed.
Waiting is when products are not being moved or processed; it should not lead to overproduction, in batch production much time is spent waiting in queues.
Movement is unnecessary travelling of products, people or equipment.
Inventory is materials, products or work in progress and binds capital; this incurs cost and is therefore waste.
Transportation does not add any value for the customer and is therefore considered waste. Transportation also exposes products for risk of being damaged or lost.
Over-processing is when more work is done than required by the customer and therefore not paid for. This can be better tolerances or more complex solutions than requested.
Defects, scrapped products or rework due to quality problems is waste.

5.3 Six Sigma

This section will present the Six Sigma framework, methods and theory since the practical improvement project that is part of this thesis is done using some Six Sigma tools. As Lean tools are used together with Six Sigma tools in the project they will be presented together in this part, there are more tools than will be presented in this thesis but restrictions has been done to increase readability and relevance, for the interested reader there is extensive literature on the subject, see the references for further reading. Some discussion and critique regarding Six Sigma will also be presented as well as a discussion about the joining of Lean and Six Sigma.

"(Six Sigma is a) business process that allows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction."

-Mikael J. Harry[14]

Six Sigma was developed by Motorola in the 1980's as a toolset to deal with quality conformance problems. The reason for the development was the purchase of a Motorola factory by a Japanese company in the 1970s which soon after the purchase was producing at 1/20th the error rate compared to Motorola; this obvious lack of quality on Motorola's part caused the development of Six Sigma[15]. The name derives from the goal to reduce quality defects to the size region of six standard deviations, which translates to 3.4 defects per million produced products. Six Sigma relies heavily on the use of statistical methods to identify quality problems. Improvement projects are often led by individuals trained in the methods and tools of Six Sigma, these people are referred to as Champion or Sponsor, Master Black Belts, Black Belts and Green Belts. The projects carried out are done in similar steps which are predefined and has predefined targets, there are two different types of projects, DMAIC for existing processes and DMADV (or DFSS) for new products or processes. As mentioned above DMAIC stands for Define, Measure, Analyse, Improve and Control while DMADV stands for Define, Measure, Analyse, Design and Verify. DFSS simply stands for Design For Six Sigma. This thesis will use the project form DMAIC for the practical improvement project. The mindset used when solving complex problems with DMAIC is illustrated in this figure, each phase of DMAIC has a number of tools.

[14] Magnusson et al. 2003
[15] Pyzdek et al. 2009

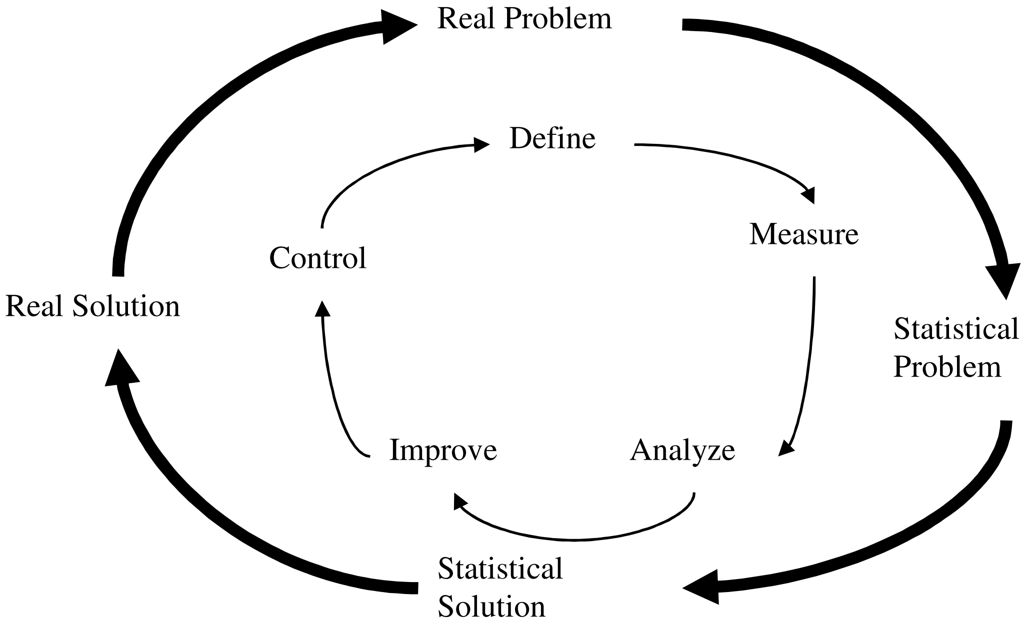

Figure 5 The Six Sigma+Lean Toolset[16]

5.3.1 The Phases and tools in DMAIC

Commonly used tools in DMAIC projects as described in Six Sigma Handbook[17], some of these will be described in more detail below.

Project Phase	Candidate Six Sigma Tools
Define	Project charter Process map SIPOC Benchmarking Project planning and management tools Pareto analysis
Measure	Measurement systems analysis Process behaviour charts (SPC) Exploratory data analysis Descriptive statistics Data mining Run charts

[16] John et al. 2008 p.11
[17] Pyzdek et al. 2009

	Pareto analysis
Analyse	Cause-and-effect diagrams Tree Diagrams Brainstorming Process behaviour charts (SPC) Process maps Design of experiments Enumerate statistics (hypothesis tests) Inferential statistics (Xs and Ys) Simulation
Improve	Force field diagrams FMEA 7M tools Project planning and management tools Prototype and pilot studies Simulations
Control	SPC FMEA ISO 900x Change budgets, bid models, cost estimating models Reporting system

Figure 6 List of Six Sigma tools

5.3.2 Define

The define phase is meant to describe the specific problem, determine the goals, schedule and the exact scope of the project. It also describes the key customers to the process and their critical requirements. During the define phase it is also important that the project gains acceptance among those involved.

Tools
Project charter
Stakeholder analysis
Kick-Off meeting

The project charter lists the business case describing the starting situation, the problems and goals in measurable terms, the scope and the roles of the people involved. It is an important tool to get an overview of the project and make sure everyone understands the purpose and goal of the project.

The stakeholder analysis generates support for the project, and if there is resistance towards the project that is dealt with. It can be on a person to person basis in the forms of training.

The Kick-Off meeting is also supposed to build support for the project but also generate involvement and integration of the team members. During the kick-off meeting the projects importance and significance is described. After the meeting every member should know and understand his or hers role in the project. The kick-off meeting can be followed up by team building exercises if that is thought to increase the chance of success for the project. Sometimes such actions may be necessary, especially if participants are from various parts of the company.

5.3.3 Measure

The major function of the measure phase is to gather data on which the analysis can be made. It is also supposed to verify the accuracy of the data and relevancy for the problem at hand. It is easy to measure the wrong things and not capture the important aspects of the problem and therefore the process should be defined as well. In the measure phase the input factors and their related output should be identified, a mental model where input factors and their variances are affecting the output and the variation of the output can be used[18]. Variation is viewed as one of the biggest threats and the root cause to quality defects. The performance of the process should also be measured in this stage in order to compare changes so that improvements can be visualized.

Tools
Data collection plan
Data source analysis
Variation

The data collection plan simply describes when and which data will be collected by whom.

Data source analysis serves as a tool to reduce the effort needed to gather data, if possible already gathered data should be used in order to save time.

The variation of the collected data is an important tool in order to give an understanding of the accuracy and behaviour of the data, valuable

[18] Magnusson et al. 2003

information about the data can be found by visualizing and studying the distribution of the data.

5.3.4 Analyse

In the analyse phase the causes for problems are verified and relationships between input and output of the process are identified and verified. Focus is on root causes of problems. What tools to use depends a lot of the problem and what process that is studied.

Tools
Process flow chart
Spaghetti diagram
Value analysis
Value stream map
Group technology
Factory layout

A process flow chart maps the processes in a way easy to overview. It gives a better understanding for the people involved; it secures a common understanding as well so as to eliminate any misperceptions among the team. This map is the building block on which the more in-depth and advanced analysis is based. The flow chart also helps visualize how complicated a products flow may be.

A spaghetti diagram is essentially the same thing as a process map but with the added dimensionality of physical distances. This easily shows suboptimal layouts in the factory floor layout and waste in the form of transportation and queues.

A value analysis distinguishes which activities are value-adding, non-value-adding and value-enabling. Non-value-adding activities are also referred to as waste. This is a very basic tool which could be very useful in determining what to focus when considering process improvements.

The value stream map is a very important tool which gives a lot of information in an easy to understand way; some key data which may be put into the VSM is cycle times, inventory levels, number of operators and an overview of the information flow in the company. The value stream map separates waiting time and value adding time making it easy to identify waste. Since much problems stem from long lead times it can be a very useful tool in visualizing waste. A common method when creating the value stream map is to draw the map by hand with representatives from the entire organization present; usually it is a good idea to follow the product through the shop floor physically. Later the map can be drawn using software and analysed in order to create the future state value stream map.

Factory layout; see Factory layout 5.8.

Group technology; see Group technology 5.9.

5.3.5 Improvement

The improvement phase is when solutions to the found problems are generated and the best solutions are chosen for implementation. If the work in the previous phases has been successful the solutions will address the real root causes and they will be based on real data reflecting the reality.

Tools
Levelling/Heijunka
5S
Setup time reduction or SMED
Future value stream map
One piece flow
Statistical process control/+QDIP

Heijunka is production levelling by both product mix and volumes. The idea is not building products according to customer demand which may swing up and down but instead take the total volumes for a period and use this data to create a mix and volume which is the same every day. By analysing pattern and volume of the customers demand it is possible to convert this demand into a levelled schedule every day, a mixed-model production.[19]

5S is a fundamental strategy for keeping the workplace organized and neat, the acronym stands for Sorting, Straightening or setting in order, Sweeping or shining, Standardizing and Sustaining. Implementing 5S helps keeping the workplace efficient and safe by keeping everything in its own place, nothing in excess and everything clean. Originally the 5S'es come from the Japanese terms Seiri, Seiton, Seiso, Seiketsu and Shitsuke.
When sorting a workplace it is a good idea to eliminate everything that is not needed, a good idea is to remove everything and only put those things back that are needed in the near future. Straightening or setting in order

[19] Liker J. 2003

means that everything should be in its place, every item should have a clearly marked position and items that are not needed on a daily basis should be put away. The items that are needed the most should be nearest. Sweeping or shining means that the workplace should be kept clean at all times, when machine equipment is kept clean dirt or oil spills can be used as indicators of maintenance needs. In order to maintain the cleanliness cleaning should be part of every day's schedule, for instance the last part of everyday could be dedicated to cleaning. Standardizing means that every workplace used for the same type of job should look the same with the same tools in the same place; a worker should be able to move between workplaces without having to look for tools. Sustaining is the last S and concerns the previous 4S. In order not to revert to old ways, standards has to be set and the previous 4S should be reviewed and improved as the business evolves.

Setup time reduction or SMED is an important tool to reduce batch sizes and improve system flexibility. SMED is the lean concept and stands for Single digit Minute Exchange of Die and is the idea of completing a changeover in a single digit of minutes, hence less than ten minutes. The steps involved in performing SMED improvements are the following:[20]

- Separate internal from external operations
- Convert internal setup operations to external
- Standardize function, not shape
- Use functional fasteners or eliminate them
- Use mediated jigs, centering can be done as an external setup if jigs are standardized
- Use parallel operations, if it is possible to split the job on two people instead of one the setup time can be cut in half
- Eliminate adjustments; screws have an unlimited number of settings while switches have a finite number
- Finally use mechanization

These steps are derived from the car industry but they can be generalized and applied in almost all types of manufacturing.

Future value stream map, this is how the process should look like in a future state, the goal of an improvements project. The time horizon can be anything from a couple of weeks to years. The future state value stream map is created when a present state value stream map is analysed for

[20] Shingo S. 1989

improvements, from the future state value stream map the activities needed to reach the goal can be identified.

One piece flow is what it sounds like, a batch-less production, often in a cell, where products move from station to station one by one. The advantages of doing this is greatly reduced work in progress and lead times, producing this way also exposes imbalances and other problems that can thereby be corrected.

Statistical process control is the measuring and monitoring of a process outputs in order to ensure the stability and effectiveness of the process. By using control charts it is easy to analyse the variation and draw conclusion as to whether the process is stable. Statistical process control can be used together with other KPI’s such as OEE, overall equipment effectiveness, which gives an overview of the total utilization of equipment used in a process. OEE measures the aggregated utilization based on three metrics arranged in a hierarchy; availability, performance and quality. There is also a top hierarchy called loading which gives the measurement TEEP, total effective equipment effectiveness.

By presenting control charts and other process control measures on the factory floor operators themselves are able to suggest corrective actions and continuous improvement actions. These are then implemented by the responsible people. One way of presenting such statistical measures in a visual way is the +QDIP sheets, these sheets simply consists of the letters +, Q, D, I, P which could stand for safety or health, quality, delivery, inventory and productivity, any other definition is possible. The letters are divided into fields, for example 25 fields for 25 working days in a month, and these fields are coloured red or green every day based on underlying criteria, for instance a DPMO of less than 100. When the days go by it is easy to see how well a certain process or manufacturing cell is performing.

Figure 7 Example of a +QDIP letter at the end of a month

5.3.6 Control

In this phase the optimized process is controlled, measurements that accurately describe the process are chosen to be monitored in the future. All in order to secure that the optimization is maintained long term.

Process documentation is important in order to standardize and document the improvements. This enables employees to be trained and knowledgeable about what has changed.

A process monitoring plan is critical to uphold the improvements. It clarifies how the process will be continuously monitored and what response by whom is necessary if a problem is identified. For example when the process does not meet the satisfactory standard specified. The monitoring plan can contain control charts that are updated continuously with measurements that are chosen for their accuracy in describing the process. The control charts should identify changes in the process that need to be adjusted. The process monitoring plan could also contain plans that stipulate how to deal with process changes. These changes are inevitable as processes change with time and it is important to make sure the optimization is not endangered by these changes but maintained.

5.4 Lean and Six Sigma

"What has been will be again, what has been done will be done again; there is nothing new under the sun."

Old Testament[21]

The joining of Lean and Six Sigma is one of the latest production management philosophies. The idea is to join two of the most successful philosophies into one. When reading about lean six sigma it is clear that no unified approach exists, instead each author has his or her own view of how to implement this strategy. The reader understands then that there are multiple viewpoints, but essentially lean six sigma is the joining of the six sigma improvement project structure and tools with lean tools and ideas of waste and value. In the improvement project carried through during the course of this thesis the six sigma structure will be used with incorporated lean production tools and ideas.

[21] **Ecclesiastes 1:9**, Old testament

5.5 Lean, Six Sigma and SME

Lean and Six Sigma implementation in Small and Medium sized Enterprises is a debated question, there are conflicting findings on whether implementation is higher in larger companies or not. Bonavia & Marin[22] discusses the conflicting findings of lean implementation from several different authors and concludes that it is indeed difficult to implement the whole set of practises for a smaller company and instead they often choose to implement a smaller subset of practises that they can afford. Thomas, Barton & Chuke-Okafor[23] claim that there is a low application of statistical methods in smaller companies and that there is a lack of sufficient theoretical knowledge in management to see the potential benefit of these tools. They even go so far as to say "In many cases they (management), and their employees, even become frightened when statistical tools are discussed." In the end they also recommend that a smaller company's primary focus should be to undertake the project in the most cost efficient manner in order to be able to recoup the cost as fast as possible. One of the most important ways of achieving this should be to undertake lean six sigma project in-house instead of hiring costly consultant expertise.

5.6 Critique

One critique is that Six Sigma is simply old practices put into a new package and given flamboyant terms such as black belts. This is expressed by Joseph M. Juran in an interview[24], and it is one of the most common critiques. This opinion has some truth to it as a lot of the practices in six sigma are indeed known from before the introduction of six sigma, but the bundling of practices into a package has advantages such as ease of implementation and a wider spreading of knowledge.

Another critique is that Six Sigma is not proactive enough, that it is more of a corrective action system[25]. An improvement program like six sigma increases the awareness of the entire workforce by educating large parts of it so the criticism is not entirely fair.

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[22] Bonavia and Marin 2006
[23] Thomas et al. 2009
[24] Paton M. 2002
[25] Ramberg J. 2000

More technical criticism is that the normal distribution is not a good measure of the reality. This is true, but it does not mean that a model based on a normal distribution is not useful. Also there are arguments that the drift of 1,5 sigma is ridiculous and arbitrarily chosen. One could always argue about how many standard deviations the drift should consist of but the fact is that it is not realistic to assume that a process will not drift from its mean over time.

Lean has been criticized for inducing high level of stress onto the workers, Conti et al. raises the question "Is lean production deterministically stressful, with benefits gained at the expense of workers?" in their article "The effects of lean production on worker job stress" [26].

Lean production does contain elements which might increase stress, such as the elimination of all waste which in turn can increase the intensity of work. This increased intensity could increase the stress induced on workers, also the practice of poka-yoke, fool proofing tasks, de-skill the tasks and reduces the workers active involvement. However, lean production has other characteristics that offset these properties, a factory with low inventory is easy to navigate and frustration of fitting parts that does not come together is reduced. Also in lean production workers are given additional responsibilities in improvement projects compared to normal production, in these projects creativity is important and they can serve as a stimulating factor. The findings[27] from a number of surveys and questionnaires show an increasing level of workers stress and dissatisfaction as the level of lean production increases. This level is not linear and decreases again as the level of lean productions continues to increase, *see Figure 8*. Similar results are found for worker commitment, decreased commitment at first but then increased as lean production implementation increases.

[26] Conti et al. 2006
[27] Conti et al. 2006

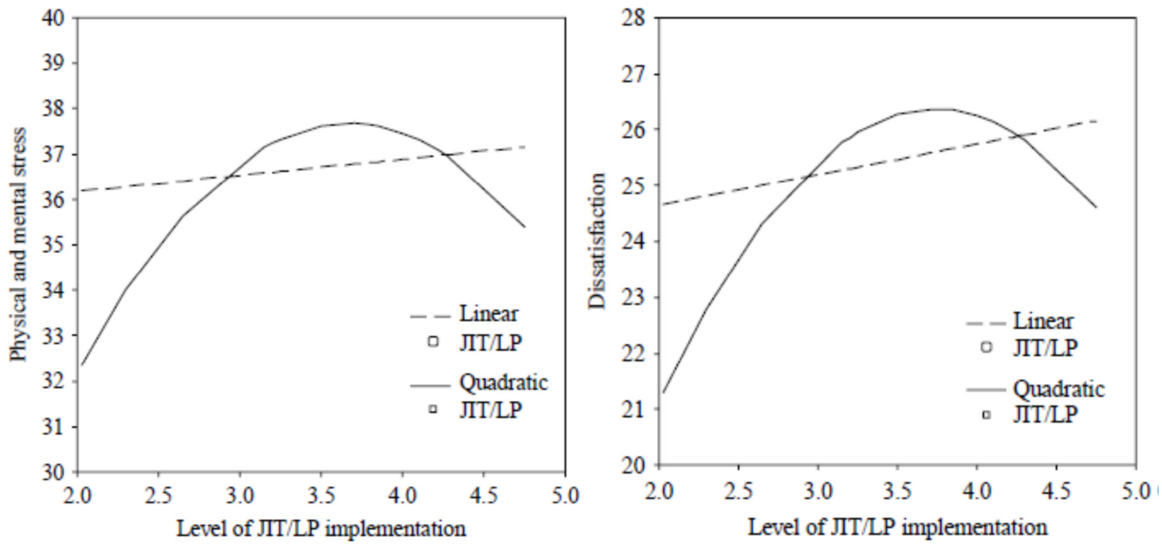


Figure 8 Level of stress compared with lean implementation from Conti et al.

5.7 Manufacturing flexibility

There are several different dimensions to the term flexibility; it can mean the ability to cope with variation in demand, product types, volumes or introduction of new products.[28] There are also flexible manufacturing systems, usually automatic NC systems designed to handle different types of products efficiently.

The ability to cope with the introduction of new products is vital and plays a key role in most companies, especially in companies with a large range of products. Variation in demand is usually dealt with by using batch production since the volumes for dedicated processes usually are not available. By using batch production it is possible to handle variation in demand not only between product ranges but also for the same product but over time. The ability for processes to change fast between different products is crucial for the flexibility. Variation of product types is usually also dealt with by using batch production since it enables different process flows to be used for different products and in order to be flexible change over time are key, the shorter the changeover is, the more flexible the company will be. Variation in demand can be tackled in different ways, by keeping inventory, by maintaining free capacity of the ability to ramp up production quickly. When a company takes decisions regarding the

[28] Hill et al. 2009

flexibility of its operations it is important to look at what dimension of flexibility is needed since the dimensions differ in investment need. It is also important to consider the strategic relevance of the different dimensions so the cost can be related to the benefit of the improvement.

5.8 Factory layout

Factory layout is important for good flow, low inventories and waste elimination. A good layout is simple, easy to understand and visual, it creates a minimum of material handling and work in progress; it is also adapted to the type of production and current conditions. There are many strategic layouts to choose from, product layout, functional layout, cellular layout or line layout and in between those there are hybrid layouts. Which layout to choose is a strategic decision based on type of products, product range, order quantities, rate of new product introductions, and which aspects wins customer orders.[29] Cellular layouts are a hybrid between batch and line processes often advocated within lean manufacturing. Some of the benefits of cellular manufacturing are reduced lead times which in turn means reduced work in progress, reduced setup times and improved direct labour productivity. It also enables easier planning and easier levelling or smoothing of production. Cellular layout is sometimes referred to as group technology layout[30] as the choices and grouping of products for a cell could be done by some kind of group technology selection. Group technology is especially interesting when there are not enough products of the same type to support cellular layout. Manufacturing cells can be of many different shapes, U-shaped, straight, L-shaped and so on. The benefit of not having a straight cell layout is the ability for operators to handle several tasks within the cell which makes is easier to balance the work and capacity of the cell. An important part of designing a cell is the aspect of material handling; bad material handling can create much waste in a production in the forms of transportation, scrap and searching. Important questions to ask when considering the aspect of material is when, what and how much, the goal is to supply a production line with exactly what is needed exactly when it is needed.

[29] Hill et al. 2009
[30] Mukherjee et el. 2009

5.9 Group technology

Group technology is a manufacturing philosophy aimed at increasing production efficiency by grouping products together based on different similarities such as manufacturing processes, geometry or manufacturing problems. The key idea is to bring some of the benefits of mass production to a mixed type of production. Some of the characteristics of a group technology system are the grouping of products into families, balancing of workload between production groups, a certain degree of autonomy and the clear identification of manufacturing cells on the shop floor. By grouping products together and standardizing their activities manufacturing, engineering, purchasing and planning can be made more efficient. Grouping can enable the creation of manufacturing cells in which setup changes, unnecessary transportation, handling, inventory and lead time are reduced. In a manufacturing cell it is also easier to improve quality by direct feedback between operators and because of the low throughput time, the cell can also be held accountable for the work easier. When grouping products there are several ways to group products into families which can then be further grouped into subfamilies with further internal similarities, nine ways of grouping are presented in the diagram below;

Criteria for Identifying Product Families	Examples
1. Product type. Group products of the same type or function into families.	Motors and generators.
2. Market. Group all products sold in a certain geographic market in one family.	North America, Europe; market segmentation can also be based on type of user, e.g., commercial vs., residential user.
3. Customers. Group all products sold to one or more customers in the same family.	The products for two dominant customers make up two families, the rest of the products a third family; this segmentation does not work if several customers purchase the same products.
4. Degree of customer contact. Group products according to the degree of influence the customer has on the final product.	Group all stocked items in one family, all made to order in another, etc.

5. Volume range. Group products with similar volume range into the same families.	High-volume vs. low-volume products.
6. Order stream. Group products with similar customer order patterns in same families.	Large and repetitive orders in one family, small and irregularly placed orders in another.
7. Competitive basis. Allocate all products that compete on the same basis to the same family.	Those competing on cost and speed to one family, those competing on customized design to another.
8. Process type. Group products or parts requiring similar processes in the same families.	All assembled products in one family, all non-assembled products in another, etc.; within each group, products with similar routings form a family.
9. Product characteristics. Group products with same physical features or raw material into families.	Large vs. small, light vs. heavy, etc.

Table 2 Nine different ways to group products[31]

To support this kind of classification of products some companies use a coding system for the properties of parts and then use this coding system to divide products or parts into families to be produced together. This type of system is often best when there are large amounts of different products to categorize; it is less useful for a lesser degree of diversification because of the costs associated with it. When there are lesser amounts of products and lesser degrees of diversification it is more useful to choose a method of clustering which does not require as much administration.

5.10 Group dynamics

5.10.1 Worker commitment

When introducing change into a workplace it will most likely bring about emotions and turmoil since most people prefer to do things in the same way as they have been doing and are used to. People want to do what feels safe and is well known. Because of this many initiatives to improve fails when people return to their old ways. This is one of the reasons a lot of the literature dissuades the use of consults, they will by definition disappear and when they do, things are very likely to reverse to the way they were before. Lean manufacturing advocates worker involvement and responsibility, pushing responsibilities down in the organization to the factory floor

[31] Hyer and Wemmerlöv 2002

enables a long term change when workers understand the benefits of the change. To do this, education and empowerment is needed, otherwise the understanding will not be great enough.

5.10.2 Change teams and FIRO

When starting improvement projects it is often a good idea to set together a cross functional team with representatives from the entire organization. In order to get this team to work together in the best possible way it is important to consider group dynamics. One such model is the FIRO model created by Will Schultz in 1958[32]; this model stipulates that a group of people will go through three stages with two resting phases in between. The three main stages are inclusion, control and affection and in between these are the two resting phases were people will be content and relax in order to regain some energy. The first phase inclusion is when people first meet and ask themselves the questions. Do I want to be here? Do I fit in the group? Am I accepted by the group? And do I accept the other members of this group?

After this initial period where everyone has accepted each other, there is relief and contentment in the resting phase before the second phase starts. In the control phase the roles of the individuals in the team are shaped, this phase often contains struggles and confrontations. Questions often asked in this phase can be. Is my competence recognized? Do I recognize the others' competence? In this phase it is important to focus on the task and not end up in conflicts. After the control phase the group goes into the resting idyll phase where everyone is happy that the conflicts have been resolved. The third and last phase affection is when the group is a team and this phase is the most productive one as everyone is focused on their own task and is comfortable enough to disclose their strength and weaknesses.

According to Schultz a team can at any time fall back from the attention phase to one of the previous phases again, especially if there is an event such as the disappearance or inclusion of a new member. If a project leader uses this model it is possible to avoid unnecessary conflicts and enable a faster teambuilding and in the end a higher probability of achieving his goals.

[32] Tonnquist B. 2009

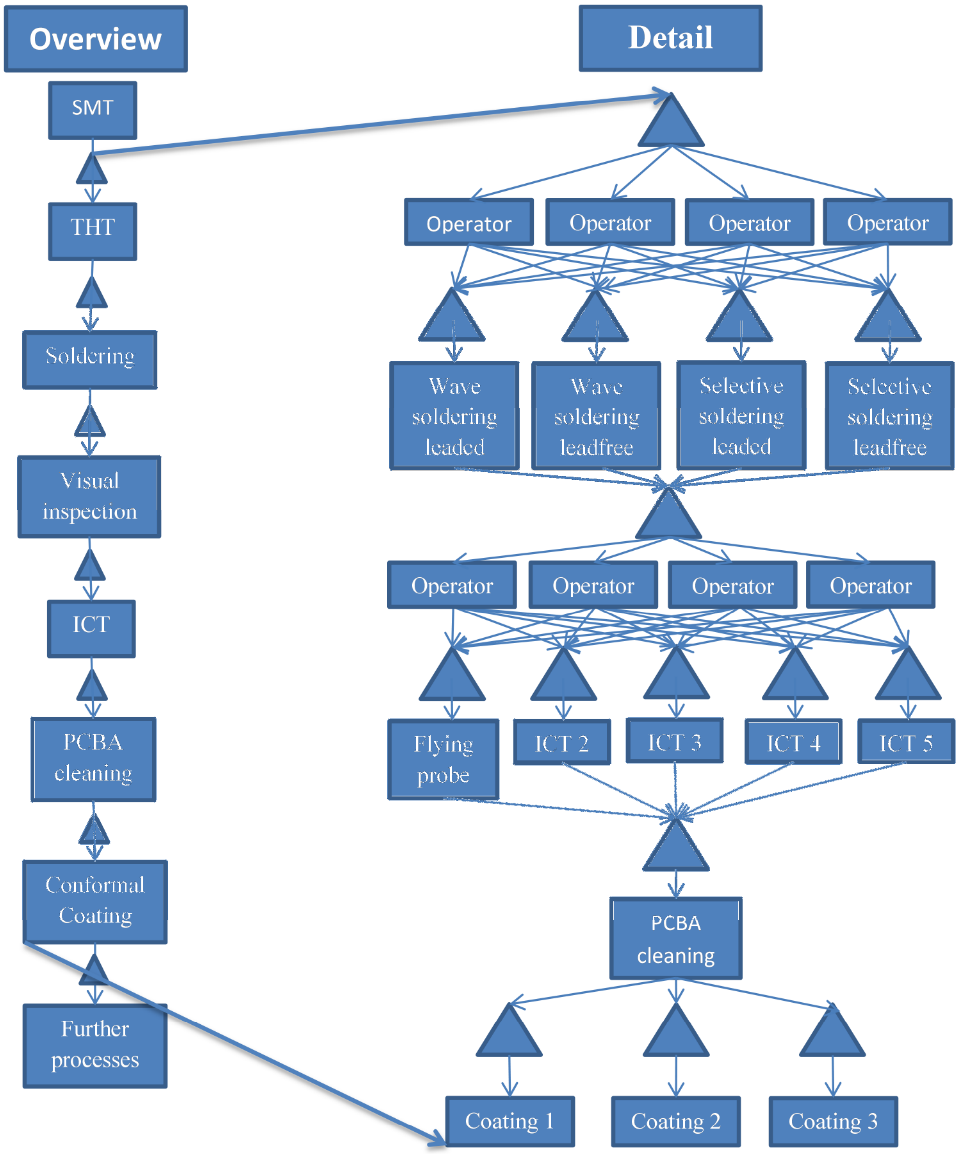
6 Define

This chapter presents the define step in the DMAIC improvement project, which is the empirical part of the thesis. Define is the first step and lays the foundation for what will be done later, after the define phase everyone involved should have a good understanding of why the project is needed, what impact it is intended to have and how it will be implemented.

Much of the work done in the define phase has been done by Magnus Kristensen, planning and logistic development manager at Enics, prior to the start of this thesis in order to motivate a master thesis being done at Enics. The delimitation to focus at parts of the Kanban line was also done prior to the definition of the thesis itself. The problem studied has been known by the planning department at Enics but the time to investigate potential solutions has not been available. Complaints from customers are common but accurate statistics regarding the number of complaints are not available. The complaints often concern delivery times and sometimes defective cards but this is not as common. Problems with the current processes are bad productivity, very high work in progress, long lead times and several long queues. Accurate data as to how large these problems are is not available and this will be part of what needs to be done in the define phase. In order to grasp the extent of the problems average queues, lead times and work in progress will be measured.

6.1 Process overview

In order for the reader to have a good understanding of the thesis the processes are presented and the parts of manufacturing considered in this report are specified.



Process overview

6.1.1 Automated assembly of PCBAs

Printed circuit boards are printed with solder paste, mounted with surface mounted components and heated to solder the components in place. This is done in automated surface mounting machines loaded with reels of components. This process will not be studied in this thesis, although problems with long changeover time and lack of components are known.

The long changeover cause large batch sizes and an uneven flow for the rest of the shop.

6.1.2 Manual assembly of through hole components

Most boards require additional connectors screwed in place and through-hole components mounted, this is done by hand in different groups. One of the groups is controlled with Kanban cards and this is the group where the boards studied pass through. Before boards enter manual assembly there is a queue of incoming parts where they are stored order wise in racks. Next to the manual assembly area the components needed for each job are stored on shelves sorted by job types; the refilling of components is done by the storage staff several times per day. Each new job also requires printing of so called mol-lists which contain all the operation steps and components as well as the order number and some additional information such as number of boards and type of board. The setup time for each new job is quite long, roughly around 20 minutes.

6.1.3 Soldering

Components from the previous process are soldered in lead free machines or in machines with lead based solder. The machines consist of two wave soldering machines and two selective soldering machines. Some cards are also partly soldered by hand. The boards initially looked at pass through the selective soldering and the wave soldering machine. The selective soldering machine is semi-automated and has a small conveyor on which the boards enter and leave the machine. Monitors display the actual soldering being performed in the machine and on these the operator can monitor the process in real time and high detail. The changeover in this machine requires a new program being loaded and the adjustment of the width of the conveyor, the time it takes for this is approximately 10 minutes. Also part of this process is inspection of the soldering, labelling of boards and depaneling by scoring or V-cut. Scoring or V-cut is when multiple printed circuit boards initially held together are separated with a simple rolling blade sliding through a score. If the soldering in the machine is not done properly it is redone by hand during the inspection.

6.1.4 Visual Inspection

After soldering most boards return to the area of manual assembly for visual inspection. The steps involved in inspection differ between boards but involve a visual control of components, the soldering previously done, labelling and sometimes breaking off of extra pieces of printed circuit board. If an error is discovered it is corrected by resoldering or exchanging of a misplaced or missing component.

6.1.5 ICT

All boards are tested in ICT where some boards are loaded with software and circuit tested. The test is performed by placing the boards by hand in a fixture with a bed of nails making contact with test points from below, this is done by hand for most boards but an automated flying probe machine is also available. None of the boards studied is tested in the flying probe machine. If a card is found to be faulty it is retested immediately or in the end of the batch/order. If the card is again found to be faulty the operator or someone nearby with the appropriate competence tries to identify the fault and repair the card, most of the time the error is found and corrected. Each board has its own fixture which is custom and handmade, thereby making it very expensive. For this reason there is only one fixture for each type of board. There are also adapters between fixtures and testing equipment, therefore the changeover takes 10 or 15 minutes depending on whether the adapter has to be changed as well as the fixture.

6.1.6 PCBA cleaning

Boards are cleaned prior to spray-coating in order to ensure the quality of coating; this is done in a single washer. All boards are mounted in baskets that go through four baths and a drying step in the machine, there is an in and out queue in the machine. The cycle time for boards in the machine therefore only depend on how many boards can fit in one basket and there is no change over time. After cleaning all boards are dried either in ovens or in room temperature for a specific minimum amount of time, usually in the range of 12-24 hours

6.1.7 Conformal coating

All boards considered in the report are coated selectively by a robot. There are three different spray-coating machines, two of which are automated and one which is semi-automatic. After coating boards pass through an oven in order to dry and harden the coat. UV light is used throughout the process to inspect the coat as it is fluorescent in UV light. In the automated machines a conveyor and feeding system transports boards from the rack into the spray robot and into the oven. After the oven the boards are fed into another empty rack. The time it takes through the oven is 20 minutes for machine N and 25 minutes for machine C. This makes changeovers very time consuming as the width of the entire length of the conveyor has to be adjusted and this cannot be done until all boards of the previous batch has passed through entirely. After coating some of the boards are manually inspected and supplemented card by card while others are only sample checked.

6.1.8 Other steps

After these steps some cards go through a burn in test designed to test them in the environment they are designed to be used in. Some cards are assembled in mechanical enclosures and then sent to packing, yet others go directly to packing and shipping. These different processes are not considered in this report.

6.1.9 Buffers

Between each and every one of these different steps there are buffers (storages) separating them from each other. The average sizes of these buffers have been estimated for the eight products initially studied (further presented in next chapter) and the result can be viewed in Supplement 1. The buffers are using FIFO to control the flow of products but in some processes, where setup times are highly dependent on which products come in sequence, operators use their experience to select products in a different order from the FIFO order, in order to speed up the process. Such process is the conformal coating where setup time can be 0-20 minutes depending on if the next order is of the same width or not.

6.2 Project charter

In order to specify the project and depict the problems briefly and clearly for everyone involved a project charter is done. This will make sure everyone understands their roles and what the project is supposed to do. The project charter is updated or reviewed throughout the project as new information is discovered and changes are deemed necessary. The charter contains information about the business case, the problems and the possible goals, important people involved and their respective roles, focus and scope of the project and important milestones. The primary goal is to investigate the possibility of implementing a lean cell for kanban products and thereby reducing inventory and lead time and improving productivity. A possible implementation is estimated to reduce work in progress by 60-70% and improve productivity by 20%. The project charter can be viewed in Supplement 2.

6.2.1 Process mapping

Among the first things that are done is a high level process map in order to give an overview of the processes studied. As there are several products studied the process map is somewhat messy and separate process maps for each product are also made later in the measure phase. The process map for all products can be viewed in Supplement 3.

6.2.2 SIPOC

During the kick-off meeting it is decided that a SIPOC diagram would be made as well, but during the process when the separate product specific process charts are made it is decided that a SIPOC diagram will not contribute to the understanding of the processes and this step is cancelled.

7 Measure

This chapter will present the second phase of the DMAIC improvements project, the measure phase. This part consists of data collection from within the production and process mapping on product level. Several different types of data will be collected, from time registration of whole orders to timing of the actual production of single boards. Some of the steps involved here are repeated later for the analysis but what is part of the measure phase is only an as-is analysis. Also quantitative data is gathered from operators in the form of descriptions of their work methods. This turned out to be an important step since the information on work methods and steps provided in the internal documentation did not prove to be accurate in all cases. These interviews were performed in an informal way in the production in order not to make subjects interviewed feel interrogated. Actual timing of production was also attempted to be somewhat discreet but the fact that workers feel intimidated could not be avoided, despite this the author feels that times gathered by hand is accurate.

7.1 Products

The eight products which are measured is a selection received from production management and they are the products in the kanban line. They are supposed to be representative for the more high volume end of production and the quantities are in the range of a thousand to tens of thousands per year. The products are the following:

3EST000212-7886
3EST000212-7864
3EST000208-8466
3EST000208-8476
61430001-UP
3EST125-973
3EST53-610
3EST113-793

The production is done in batches which correlates with customer orders, therefore some products sometime varies in numbers, there is no completely fixed batch size. This is not a major problem as orders are of the same size most of the time. The product share is depicted in the following diagram:

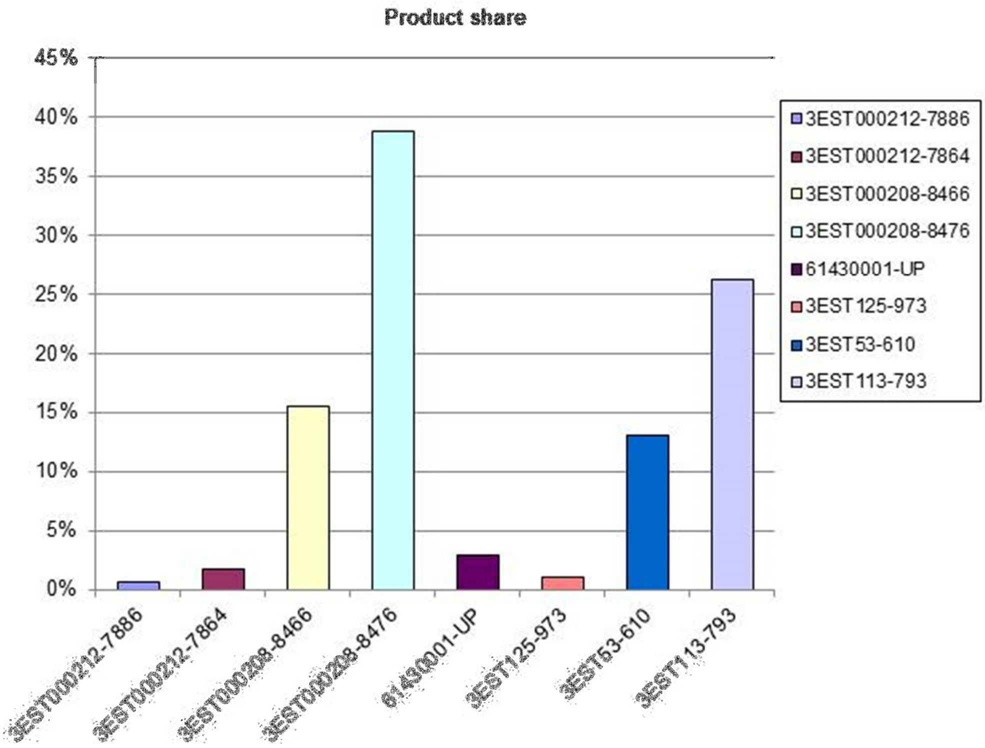


Figure 9 Overview of the products shares

7.2 Time registration

Enics has a time registration system in the production. Employees scan the bar code of the production order into a computer as they start the production and when the order is finished in each process step. They are also supposed to scan a start and stop of the order when a pause in production occurs, for instance when a break takes place. Theoretically it should therefore be possible to get production time for each product and process, however this time registration is not being used properly. Breaks such as coffee breaks or lunch breaks are normally not registered and often either start or stop has not been registered. There is also often the problem with the bar code scanner misinterpreting the bar code and therefore there is a lot of order numbers scanned that does not show up. Also some processes lacks the time registration altogether for various reasons, they may be deemed too unimportant or there is simply no practical way to scan them for a lack of computers nearby. Lead times are well suited to gather from the time registration since start of the first process step and finish of the last are often available.

7.3 Data collection plan and data source analysis

Data will be gathered through the time registration described above and by manual measuring with a stop watch in the actual production. The most reliable data comes from the manual collection. Apart from the time measures personal interviews with the operators and workers will be conducted in order to get a good understanding of how the work is conducted, what problems usually arise and to verify that the data collected describes the reality in a good way. Some key measures taken are cycle times; change over times, processing times, lead times, number of operators and uptime. Wherever it is possible, separation between machine time and operator time is done. Some of the data gathered is presented in Supplement 4. This data is needed for setting up value stream maps and to identify possible improvements. In order to evaluate possible changes in operation flow it is vital to have all information regarding the products in order to identify such things as balancing issues.

7.3.1 Variation

When possible the variation of the data is preserved in order to maintain information such as accuracy and reliability. The variation can also be used to see how stable a process is. If manual assembly cycle times have a large variation this is probably an indication of some kind of disturbance or quality issues.

7.4 Work in progress

Work in progress is measured by going through the production and manually writing down orders and where they are located, this is done on several occasions in order to take averages. The measurement of work in progress is important in order to understand today's situation, how it can be improved and also to show how much progress has been made.

7.5 Process maps

Each product studied differs in operation order and operation types, but there are similarities between the products. In order to visualize the similarities and actual physical path of the products the process maps are made with a physical dimension (spaghetti diagrams) as well as the process steps, the maps are not made to scale however as this was deemed unnecessary. The eight different process maps are added in Supplement 5.

7.6 Value stream map

Value stream maps, or VSM, are made for each product based on the gathered data, this is part of the as is analysis and the purpose is to display how the products are made today and how much value adding time is added compared to the total throughput time. This visualization enables a much easier analysis of possible alternative manufacturing setups later in the analyse phase. It also highlights the areas where improvement is possible by easily displaying waste in form of waiting time. The value stream maps for the eight products are presented in Supplement 6.

8 Analyse/Improve

The purpose of this these phases in the DMAIC project are to analyse the data gathered in the previous phase and to come up with possible solutions to the identified root causes. Several important tools used to aid this purpose will be presented. Some improvements will be implemented while continuing the analysis as an iterative process will be used and the chapters are therefore presented as one.

8.1 Spaghetti diagram and future process flowchart

The spaghetti diagrams and process flowcharts are analysed together with Value Stream Maps of the as is situation in an analyse kick off meeting and a couple of ideas are created for possible future changes. The problems consist of having many processes with batched production causing long lead times, high inventory and also hiding inefficiencies in the processes. Work is not standardized as all operators have their own way of doing things. The current problem with high inventory, long lead times and long queues could be reduced if some of the processes could be joined into a cell within which there would be one piece flow of products. It would be easier to standardize assembly and setups within such a cell and track the progress of improvement by implementing process control. The following Figure 10 shows an idea for a layout for a part of the production process. The idea is to have material enter into manual assembly where the one piece flow starts and continues until the in circuit testing is complete. In order to have a mix of products flow in this manner almost zero changeover times is a requirement, something that will be difficult to achieve in some of the process steps. Instead of mixing products another idea is to have a schedule of product types over the week so that a batch of one type would be produced in one piece flow and then a batch of another product, and so on throughout the week. This idea requires enough medium volume products with the same process flow so that changeovers of the entire cell is scarce enough, perhaps a few per day. It is decided that this idea will be investigated and a return into the measure phase is necessary in order to find out if such volumes of appropriate products exists.

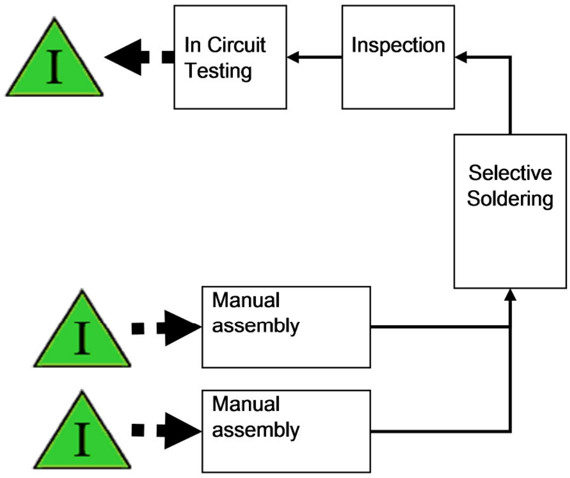


Figure 10 A simple diagram showing the process steps in a cell configuration

In order to investigate whether this setup is even possible the next task is to check volumes for all products that pass through the selective soldering and compare their operation sequences to find products with the same process flow. If this setup is possible the future VSM for the products that can pass through this cell will look like this compared to the old VSM:

	664 Units	Assembly 1	01 Units	Assembly 2	64 Units	Selective soldering	24 Units	Inspection	840 Units	ICT	32 Units
		1 Op		1 Op		1 Op		1 Op		1 Op	
	Inventory		Inventory		Inventory		Inventory		Inventory		Inventory
Cycle time											
Uptime		100%		100%		100%		100%		100%	
Yield		60%		60%		95%		80%		90%	
Change over time		20 min		20 Min		12 min		5 min		15 min	
		85		56,00		91,00		88,00		135,00	
		1 shifts		1 shifts		2 shifts		1 shifts		2 shifts	
Distance travelled		3		2		6		6		20	
Waiting time	5,163 Days		0,008 Days		0,498 Days		0,187 Days		6,532 Days		0,249 Days
Value added time		85		56		91		88		135	

	664 Units	Assembly 1	0 Units	Assembly 2	0 Units	Selective soldering	0 Units	Inspection	0 Units	ICT	32 Units
		1 Op		1 Op		1 Op		1 Op		1 Op	
	Inventory										Inventory
Cycle time											
Uptime		100%		100%		100%		100%		100%	
Yield		60%		60%		95%		80%		90%	
Change over time		20 min		20 Min		12 min		5 min		15 min	
		70,5		70,50		91,00		88,00		135,00	
		1 shifts		1 shifts		1 shifts		1 shifts		1 shifts	
Distance travelled		3		1		2		2		1	
Waiting time	5,163 Days		0,00 Days		0,00 Days		0,00 Days		0,00 Days		0,249 Days
Value added time		71		71		91		88		135	

Figure 11 Present and future value stream map

The cycle times would have to be balanced between the different stations. With a cell configuration this is not as difficult as in previous setups as workers can move freely throughout the cell and help where it is needed. The number of assembly lines currently feeding the selective soldering machine is easy to scale up and down on an hour to hour basis in order to balance cycle times in manual assembly. Primarily the utilization of the selective soldering machine is prioritized and therefore balancing will be done with this machine in mind. The balancing is probably not possible to tune into perfection, the time in soldering is not possible to affect much and when manual assembly work content is divided between two operators it is just not possible to end up with perfect balancing, if this is the case it is important to decide what the priority is; machine utilization or operator utilization. If it is not possible to balance ICT testing, this operation might have to be excluded.

8.2 Product selection

A list consisting of the products which has the largest future demand through the selective soldering is created. The list is sorted with regard to the total operation time in selective soldering and a selection of eight products with accumulated processing time of 40 hours per week is chosen. See Supplement 7. These products process sequences are noted in order to do a comparison and to check compatibility. Also a VSM for each product is made in order to be able to balance the flow within the cell for the different products. Outer dimensions of the boards is also noted, if any similarities exist this could reduce changeover time in selective soldering.

The collection of eight products is discussed in a meeting with all stakeholders. In this meeting the ambition is to get everyone connected involved, also representation from the union is present in order to create acceptance and understanding of possible future changes in production.

The products similarities are their process flow and volumes; if more volumes existed it would be possible to further select products based on other characteristics such as width and by doing so reducing setup times. Also products with the same work content would be desirable since it would eliminate the need for changing the number of workers in the cell. Even more characteristics to take into account could be ROHS (lead free) compatible PCBAs, IPC-A-610 class 3 products and some soldering characteristics in the machine. However, since these volumes does not exist it is necessary to settle with operation flow and volume. One of the possible issues that may arise is changeovers since during changeovers the entire cell will be waiting until all parts are ready and therefore it is vital to standardize and minimize the changeovers.

The hardest part of the data gathering is to find reliable demand data for one year into the future, after discussions with all master planners a list with the best possible estimate of future volumes is agreed upon.

8.3 Team creation

A team is created with more people involved than during the first part of the project. This new team consists of representatives from the union, process technicians from different processes involved (ICT, selective soldering), manual assembly coordinator, managers from production technology, production control and logistics/planning and also a production engineer/author of this master thesis. The purpose is to involve all stakeholders from an early stage so as to create acceptance for the changes that might come. The first meeting does not cover the actual products or changes intended instead it is focused towards lean principles and teambuilding. A vision is presented during this meeting, something to strive for but which may not be realistic.

During the second meeting teambuilding is also discussed but not to the same extent, also some lean tools are discussed. The idea is to present a little underlying theory each meeting and try to bring the group a little closer together during each meeting by addressing somewhat softer subjects each time. During the second meeting the results so far and the basic idea of creating a cell are presented. A process map is discussed and every person gives input on what the difficulties are on their part and what obstacles lay ahead. No actual new information is gathered during this meeting but understanding for the problem at hand is greatly improved. An initial product family is presented with the chosen products; the focus is on selective soldering which will be the center of the cellular configuration. One of the basic prerequisites is that a full shift of work for the selective soldering machine is found, this prerequisite is met with the initial product family. For specification of the products and operations involved see Supplement 8.

A second possible product family is also available but the number of products will be higher, possibly as many as 20 different products which make the task of one piece flow much more complicated. This second product family might be looked into at a later stage. The initial focus will be on the first and easiest product family.

During the following meetings participants were given tasks to do between the meetings. Possibility for SMED was analysed and solutions decided upon, one improvement is the adding of a printer for order information sheets that follow orders through the plant, previously this was located far away and much time was spent walking to this location for each order. It is discussed and decided that manual inspection should be moved and placed after selective soldering instead of inside manual assembly as it is today. In circuit testing is studied, which product is tested in which machine and if it is possible to test all products in the same machine. Information about the project will be spread throughout the company by using the existing monitors in lunch rooms where a power point feed gives information to employees. Suggestions for layouts of the cell are spawned. The different components used in manual assembly are analysed for the next meeting marking out which components are the same for the different products; this is made in order to simplify SMED.

8.3.1 Cross-functional diagram

The following diagram shows which processes/functions are involved, the process owners and the specialists from the processes.

Function	Owner/responsible	Specialist
Manual assembly	P-O Gustavsson	Eva Gunnstedt
Selective soldering	Thomas Carlsson	Thomas Hemström
Manual inspection	P-O Gustavsson	Eva Gunnstedt
In circuit testing	P-O Gustavsson	Petri Jakonen
Union representative	Anne-Lie Blomström	
Logistics	Magnus Kristensen	

8.4 Cell layout design suggestions

The following design suggestions are created, all support the intended flow but they have different advantages and disadvantages.

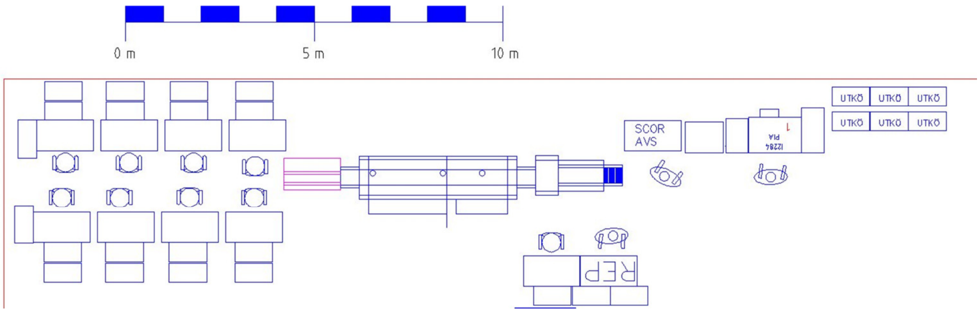


Figure 12 Straight layout

Straight layout, this is more of a line without some of the advantages that come with a cell design but it could be easier to fit into the current layout of the floor.

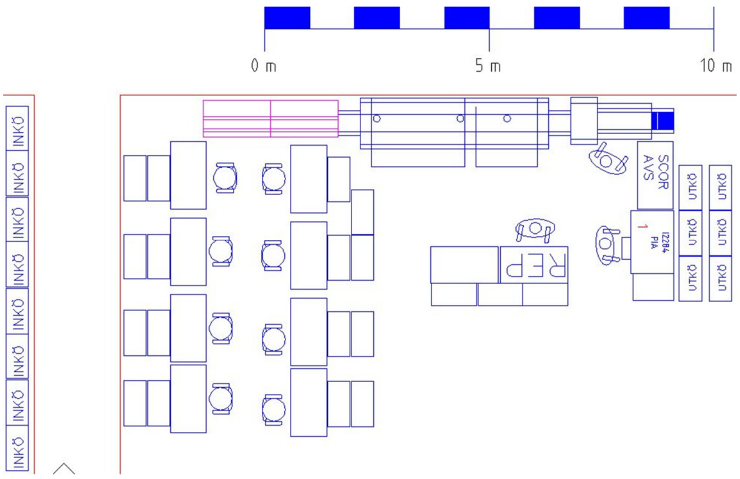


Figure 13 U shaped cell

U shaped cell layout, this is the most interesting layout, it has manual assembly feeding the conveyor into the selective soldering machine and after the machine is an area where personnel is handling the depaneling, inspection, in circuit testing and repair together with supervising the machine in case of machine breakdowns. Since the area where repairing, depaneling, visual inspection and in circuit testing is done is so small it is possible to balance these stations by dividing tasks between operators much more freely than it would be otherwise.

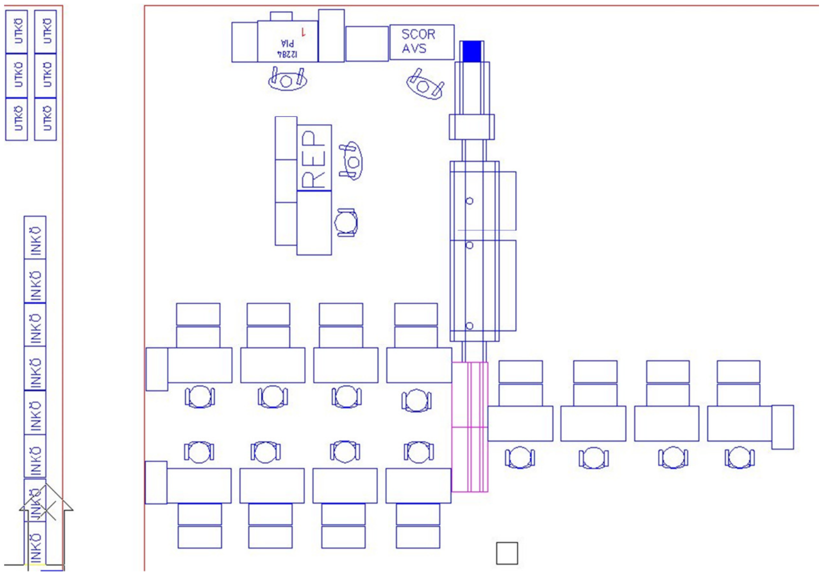


Figure 14 U shaped cell with room for added manual assembly

During the upcoming meetings it is decided that the straight line without ICT testing is possible to implement immediately by moving a few benches but that a U-shaped cell is the best solution. Since the products moving through the cell consist of such a variety of products it is vital to be able to balance the products by having operators move between inspection, labelling, depaneling and manual assembly and this balancing is best supported by a U-shaped cell configuration. In order to create a U-shaped cell configuration the machine has to be moved and this move requires redrawing of electricity, ventilation and nitrogen supply, something which needs planning but will be done in the future. Another obstacle is that all the soldering programs have to be revised by the process technician after a move of the machine because of the sensitivity of the machine, but this is not a major problem. There is no solution for the balancing of the ICT testing. Priority one is the test coverage on the PCBA's and the production flow is of second importance to customers. Due to this dead end a separate project is created where the test department will discuss production flow and this is taken out of the scope of this project.

8.5 5S, TQC

5S have been implemented earlier but degraded over time so a fresh start is needed. The proper tools and working instructions has to be available for each work station. In order to shake things up and get people in the right mindset the workplaces are shifted as an initial change, also tools and proper working instructions are placed on each workstation, these are unique for the specific products meant to be produced at each workstation. In the updated work instructions balancing and TQC are implemented, the idea is to introduce this work method before the actual changes are made later so that all staff is familiar with this way of dividing work between each other and also the control of previous work at each station.

8.6 SMED

A place for printing order information will be added close to the group so that it is no longer necessary to walk the distance to the printer and back again. To begin with this preparatory work is done by the line coordinator prior to production. Shadow boards will be used at each work station in order to avoid the search for tools during each setup. Another improvement is adding the components shared by many products to the workplaces so that they are always at hand when starting a new job, further reducing the setup time.

8.7 Pull system

A pull system in the form of kanban is implemented in the line; this system will be used in the new cell with some modifications. In order to reduce setup times, movable kanban shelves with material will be used. These shelves will be moved next to the operators during setup eliminating the need to pick each container by hand.

8.8 Poka Yoke

In order to minimize the potential mistakes by operators work instructions are used with colour coded components and large indicators for positions. Operators are also responsible for complete examination of both their own work and the work of the previous operation.

8.9 One piece flow

The initial scope was one piece flow through manual assembly, selective soldering, depaneling, labelling, visual inspection, ICT, washing and conformal coating. As a start one piece flow is implemented through manual assembly, selective soldering, depaneling, labelling and visual inspection. This one piece flow is run batch wise, so mixing of different products is not done.

8.10 Visualization

The queuing of orders has been done by writing down order numbers on a board from which operators read. This has led to some confusion and unnecessary searching for material. A physical queue consisting of movable kanban material shelves and movable containers with PCBs will be created next to the manual assembly line, completely eliminating the searching for jobs. In the future this is intended to be a simple FIFO buffer.

8.11 Layout

A straight line is immediately created simply by moving benches closer to the selective soldering machine; this simple change will support the new production flow until further changes can be made.

8.12 KPI's and process control

Up until now process control has been based on the knowhow of the operators, but in order to be able to measure the improvements a few KPI's will be measured on a daily basis and presented inside the manufacturing cell, this will also give the operators feedback on their work. The measurements that will be implemented is limited by the ability to measure but DPMO, lead time, productivity and sick absenteeism will be measured. In order to present the data easily a +QDIP technique will be used but with the letters +QLP.

9 Discussion

A brief discussion will follow regarding the findings and the theory behind the thesis.

9.1 General discussion

Lean manufacturing is traditionally directed towards larger companies with a smaller variety of products. This is not the case of Enics Västerås, Enics is a smaller company on a global scale and the Västerås business unit is on the verge of being classified as a SME. Globally Enics turnover was 271MEUR in 2009 which translates into a 20th position among electronics manufacturers globally. Enics Västerås turnover is around 50MEUR with roughly 260 employees. By the definition of European commission[33] and department of trade and industry[34] (DTI) a SME is a company with less than 250 employees. However, some authors consider a business to be small if it has 500 employees[35], whereas Lee[36] prefers 300 as the limiting number, and yet others choose the limit 250[37]. Considering these conflicting opinions and the fact that Enics Västerås is focused on beginning and end of life cycle products adding up to around 4500 different products, defining Enics Västerås as an SME is reasonable.

Problems with Enics status of a smaller company is leverage against suppliers. Lack of components often causes delays in production, something which is devastating to the production flow and since suppliers tend to be very large it is impossible to exert any pressure on them. Also the manufacturability of products is an issue; Enics does not own any products itself and the ability to affect the design is limited, since design for manufacturing is a crucial part of lean this hampers the implementation. There is also an issue of knowledge within the company, see the separate discussion below in part 9.3. This being said there is much to do, lean implementation in its fullest needs some kind of repetitive production, but in most job shops there is a degree of repetitive production. By examining the volumes it is possible to form product families which can be treated as repetitive products and for these products it is possible to set up dedicated

[33] SME definition 2003
[34] DTI Press release 2005
[35] Bonavie et al. 2006
[36] Bonavie et al. 2006
[37] Bonavie et al. 2006

cells and pull systems. This simplifies the implementation as changes affect large quantities of the production, giving large benefits. By treating these products differently from the lower volumes large benefits can be gained, the rest of the product flora should be treated as normal job shop products with batch production. This doesn't mean that there are some techniques that could be applied to this part of production as well, by using SMED and 5S changeovers can be simplified and batch sizes reduced. Multi skilled workers who are flexible and can move to where they are most needed are also very useful.

9.2 Cell implementation

The initial scope was to investigate whether it was possible to create a one piece flow of products through several processes; this had to be narrowed because of limitations found during the process. Initially the scope was to create a one piece flow through manual assembly, soldering, visual inspection, depaneling, in circuit testing, washing and conformal coating. In circuit testing had to be excluded because cycle times were not possible to affect without large investments in new testing equipment. Not excluding in circuit testing would have resulted in large balancing losses and since the priority was to optimize the cell based on the machine in selective soldering this had to be excluded from the scope. Excluding this operation also meant that the operations after it had to be excluded. In the end a cell consisting of manual assembly, selective soldering, visual inspection and depaneling was proposed.

One large challenge was to identify appropriate products for the cell; the products require similar process flow so this was the first selection criteria. After this criteria there are several other to take into consideration; product mix affecting setup times, work content for balancing and leaded or lead free products, these are examples of what could be basis for selection. In Enics this problem was reduced to finding products and volumes which made the flow possible since the volumes and diversity of products is so great. In a larger company with less degree of product diversification much more advanced selection criteria could have been used which would have made the task of finding products more difficult but in turn the design of the cell would have been simplified in terms of balancing and layout. Another issue with selecting products is finding reliable forecast data, one year into the future is a very long horizon for a supplier, and usually forecasts from customers are accurate only for a few months or even less. There is no good solution to this problem; the only option is to agree to what the best estimate is. When deciding upon which layout to choose it is important to think about which principles it should support; where and how material replenishment should enter the cell, if finished goods should be leaving the cell from the same place as goods entering the cell resulting in a U-shaped cell or if a straight flow is desired. A U-shaped cell may eliminate some transportation and could also be more space efficient. It is also easier for operators to move between different stations in a U-shaped cell.

9.3 Lack of knowledge

In order to implement production methods such as lean production knowledge is needed, knowledge often received through some kind of theoretical training; be it university or other, it is not gathered on the shop floor. Practical training is essential but only after the necessary theory is known. Within SMEs this theoretical knowledge is often missing[38], approximately 55 percent of all SMEs in Sweden do not have any university educated engineers[39], but practical technical knowledge is often high through years of experience. This knowledge on different production methods is available, but the transfer to SMEs is lacking causing bad productivity among manufacturing SMEs who often have low profit margins[40]. It is crucial that SMEs start to implement systematic use of production methods in order to be competitive in today's increasingly global world. The implementation of production methods needs to be done in a way that asserts that the change is permanent and will not slowly dwindle back to the old ways. However, since implementation requires some kind of specialist support, traditionally it is done by hiring a consultant with the mentioned result of slowly going back to old ways when the consultant leaves. A way of getting around this problem is to use external specialist support to train and support the change while implementing the changes internally by trained staff. Within Sweden there exist lean initiatives aimed at SMEs in just this way, working with SMEs, helping facilitate change without doing it for them. These lean initiatives could establish contact between research organizations and SMEs by building networks and clusters of companies trying to establish new production methods. Just by using contacts with other companies as benchmarking would be useful so that companies can see which possibilities exist.

A problem within Enics is a lack of systematic measurements, when there are no good KPIs there is no good way of identifying problems,

[38] Rothenberg S. 2004
[39] Axelholm and Lagerholm 2002
[40] Von Axelson J. 2007

improvement potential and performing benchmarking. There is also no capacity planning worth mentioning, which is a serious problem when trying to create an even flow by levelling or Heijunka.

10 Conclusions

Enics Västerås faces large threats from low cost countries situated in Eastern Europe and Asia; product transfers to such sites are already a common sight within Enics and will probably continue to be in so the future, but the breaking point when a transfer is feasible is something Enics Västerås can affect. Currently there is a high pressure from top management to improve production efficiency within the sites and it is crucial for Enics to embrace the possibilities to do so. Recently the entire management has been replaced within Enics Västerås and possibly this could enable a larger scale change within the site.

There are several obstacles that need to be dealt with. Enics is lacking in financial strength, knowledge, system support, systematic use of production methods and previously management support. These are all factors that have to be taken into account, but they are not insurmountable. By doing things in house costly consulting can be eliminated. Systematic KPIs such as OEE, lead time and warehouse stock turns can be implemented without too much work. Small cost effective projects and improvements can give quick recovery of expenses and thereby eliminating the need for large investments. By implementing one piece flow wherever possible through some of the processes and by systematically decreasing setup times throughout the entire factory large benefits can be achieved. Implementation of KPI measurements throughout all processes will give a clear view of where capacity constraints exist and where improvement projects have to be aimed. Implementation of KPIs will also serve as an important tool to see the results from improvements, which is very important in order to keep working in the right direction.
Regarding the cell it is clear that this solution is feasible and continuing the cell implementation by working on improving balancing, layout and product selection should result in an efficient cell where process control is possible. In the end operators themselves should be responsible for monitoring the KPI's and standardizing the work within the cell. In the future there should be continued work with implementations of similar cell configurations, for instance in unit assembly and wave soldering. There exist many possibilities throughout the factory for further improvements if the will to change is there.

There is much to be done over a long time period and most important of all is endurance, primarily from management in the form of encouragement and support in all its forms.

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http://bible.cc/ecclesiastes/1-9.htm. Ecclesiastes 1:9, bible translations.

12 Supplements

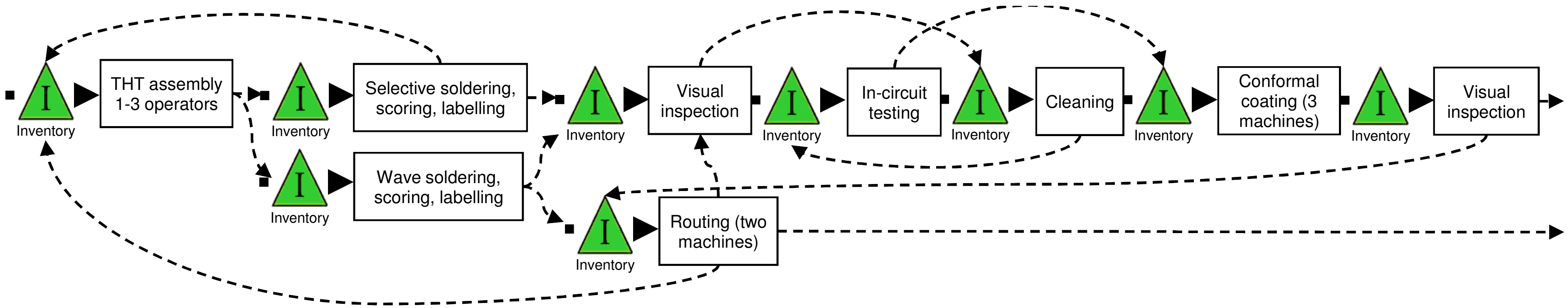
Buffer\Product	*7886*	*7864*	*8466*	*8476*	*UP*	*973*	*610*	*793*
Manual assembly	18	26	48	188	117	52	18	526
Selective soldering	0	0	8	0	12	4	0	34
Wave soldering	0	2	0	0	3	0	0	0
Visual inspection	2	8	4	4	0	0	0	56
ICT	4	10	44	68	24	4	126	717
PCBA cleaning	2	4	28	76	6	3	36	101
Conformal coating	0	14	96	52	3	6	99	201
Coating inspection	0	2	0	8	0	2	0	73

Supplement 1 Average buffer sizes

The Kaizen Event Contract

<table>
<tr><td colspan="2">Process Name: Lean cell for kanban line</td><td colspan="2">Timeline: November-Summer</td></tr>
<tr><td colspan="4">Kaizen Workshop Purpose: Implement longer Lean cell for kanban product</td></tr>
<tr><td>Process Scope:</td><td>Start at: Manual assembly</td><td colspan="2">Ends At: Coated PCBA</td></tr>
<tr><td colspan="4">Empowerment Boundaries: Team work is: Find and implement solutions for one piece flow in a longer range than today using the rules of lean</td></tr>
<tr><td colspan="2">Contract Objectives:
Improve productivity 20%
Reduce WIP 60-70%
Implement longer One Piece Flow</td><td colspan="2">Operational KPI:
Lead time, Throughput time, Inventory</td></tr>
<tr><td colspan="2">Team Members:
Magnus Kristensen — Project Leader
Per-Olof Gustavsson — Production manager
Malin Lindgren — Production engineering
Björn Ljunggren — Master thesis student
Tomas Hemström — Process specialist
Eva Gunnstedt — Coordinator
Anne-Lie Blomström — Union member</td><td>Facilitators:
Magnus Kristensen, Planning manager
Per-Olof Gustavsson ,Production line manager
Malin Lindgren, Production engineering</td><td>Process Owner (s)
Thomas Carlsson</td></tr>
</table>

Supplement 2 Project charter



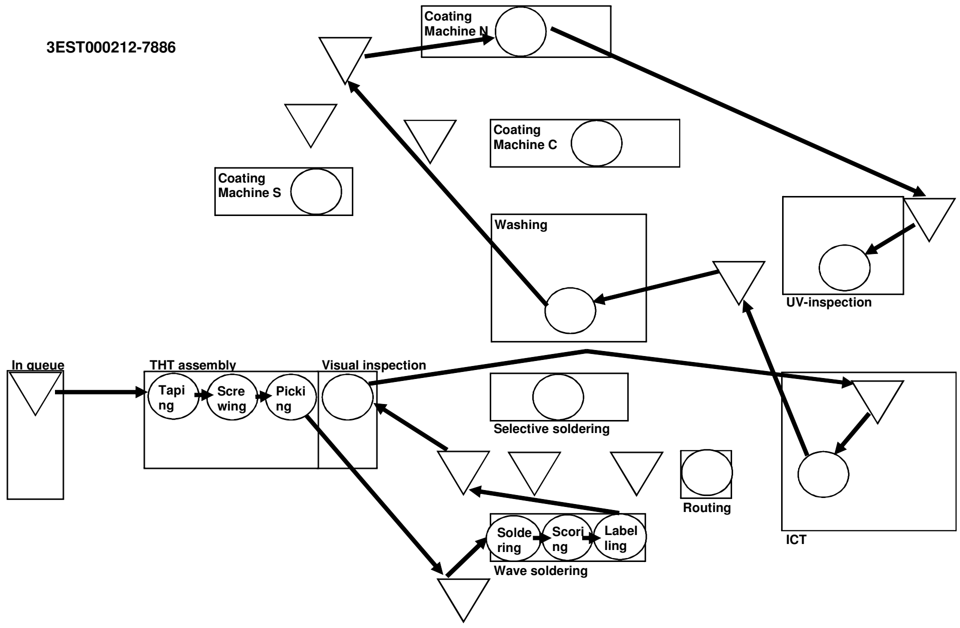
Supplement 3 Process map

Process	Product:	3EST000212-7886	3EST000212-7864	3EST000208-8466	3EST000208-8476	61430001-UP	3EST125-973	3EST53-610	3EST113-793
	Batch size	20	20	40	40	30	14	90	56
	#boards per panel	1	1	2	2	3	2	3	2
THT assembly	#operators	3	3	2	1	1	2	2	2
	Setup time	00:20:00	00:20:00	00:10:00	00:15:30	00:14:15		00:15:00	00:23:00
	Tape time	00:04:36	00:05:08	n/a	n/a	unknown	00:03:44	n/a	n/a
	Assembly time	00:03:36	00:08:00	00:00:44	00:01:51	00:05:49	00:02:45	00:01:39	00:02:49
	Picking time	n/a	00:05:05	00:00:38	n/a	n/a	00:07:48	00:02:16	00:01:53
Wave soldering	Setup time	00:05:00	00:05:00			00:05:00	00:05:00		
	Cycle time/board	00:00:39	00:00:39			00:00:20	00:00:29		
Routing	Setup time				00:05:00				
	Cycle time				00:00:40				
Selective soldering	Order time	n/a	n/a	00:28:14	n/a	00:22:30	00:13:35	01:32:00	01:24:00
	Cycle time	n/a	n/a	00:00:42	n/a	00:00:45	00:00:58	00:01:08	00:01:31
Visual inspection	Order time			00:57:11	01:23:00	01:21:05	00:32:03	02:15:14	00:44:00
	Cycle time		00:05:08						00:00:33
ICT	Setup time			00:15:00	00:15:00	00:15:00	00:15:00	00:15:00	00:15:00
	Order time			01:47:49	00:52:27	00:17:00	00:27:35	02:15:00	03:00:30
	Handling time	00:00:30	00:00:30	00:00:30	00:00:30	00:00:30	00:00:30	00:00:30	00:00:30
	ICT cycle time	00:01:40	00:01:40	00:01:00	00:00:25	00:00:05	00:00:25	00:00:10	00:01:45

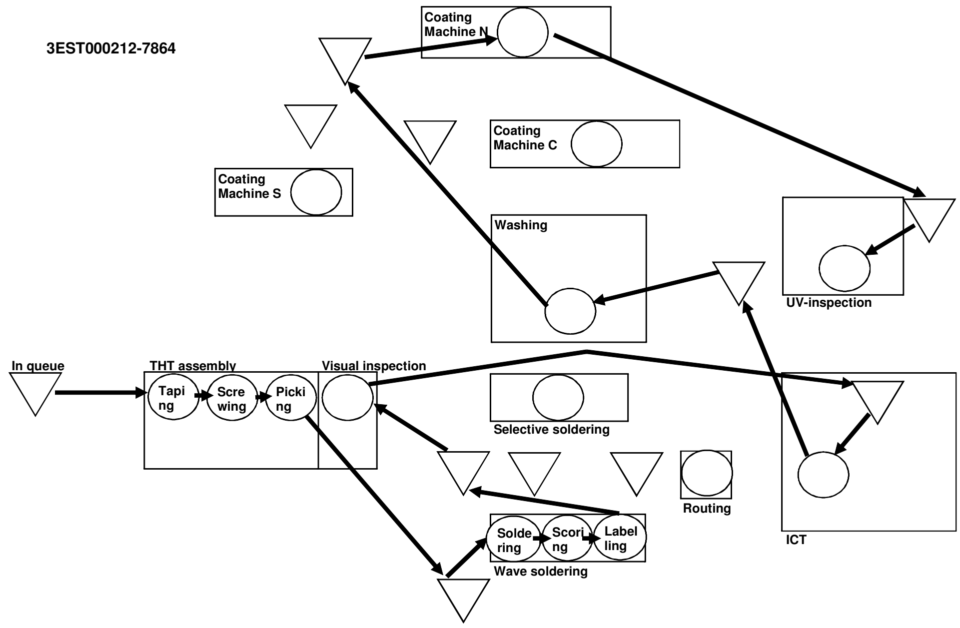
	FT cycle time	n/a	n/a	n/a	n/a	n/a	n/a	00:00:50	n/a
Washing	#baskets	3 to 4	3 to 4	2	2,5-3	1	1-2	4	4
	Throughput time	01:00:00	01:00:00	01:00:00	01:00:00	01:00:00	01:00:00	01:00:00	01:00:00
	Basket cycle time	00:15:00	00:15:00	00:15:00	00:15:00	00:15:00	00:15:00	00:15:00	00:15:00
	Drying time room temp	12:00:00	12:00:00	15:00:00	15:00:00	06:00:00	06:00:00	06:00:00	06:00:00
	Drying time oven	**----** n/a	n/a	06:00:00	06:00:00	n/a	n/a	n/a	n/a
Conformal	Machine	N	N	C	C	S	S	N	N
coating	Setup time	20-25min		25-30min					
N=snabben	Fixture handling time								00:00:27
C=century	#Boards/fixture	1	1	not in fixture	not in fixture	1	1	3	2
S=select	Time per fixture/board	00:02:30	00:02:30	00:01:20	00:01:20			00:02:30	00:02:30
Visual coating	UV-inspection	Ja	Ja	Nej	Nej	Nej	Nej	Nej	Ja
inspection	UV-inspection cycle time	00:01:37	00:02:22		00:00:17				00:00:48

Supplement 4 Process times

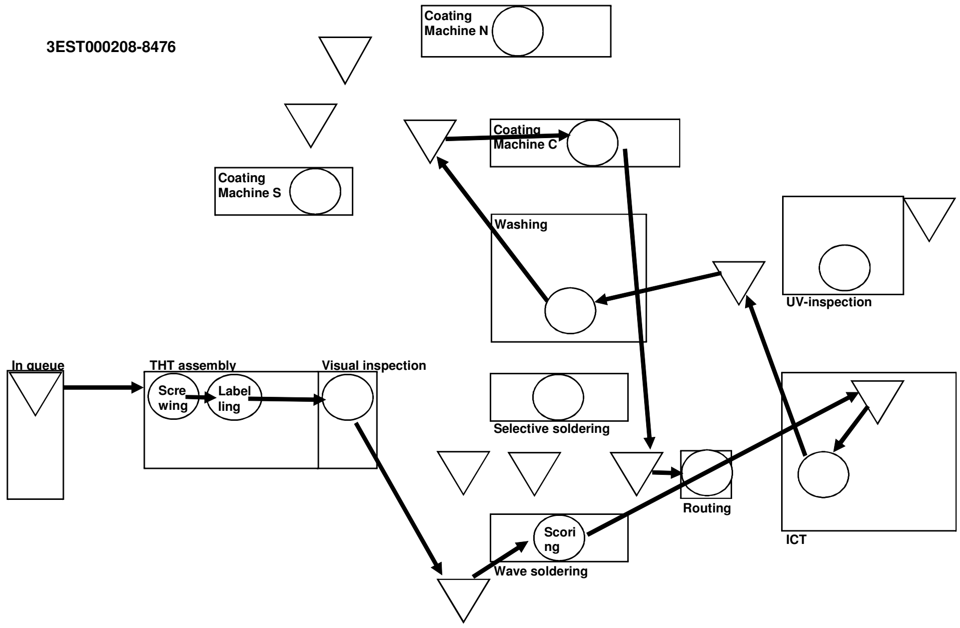
3EST000212-7886



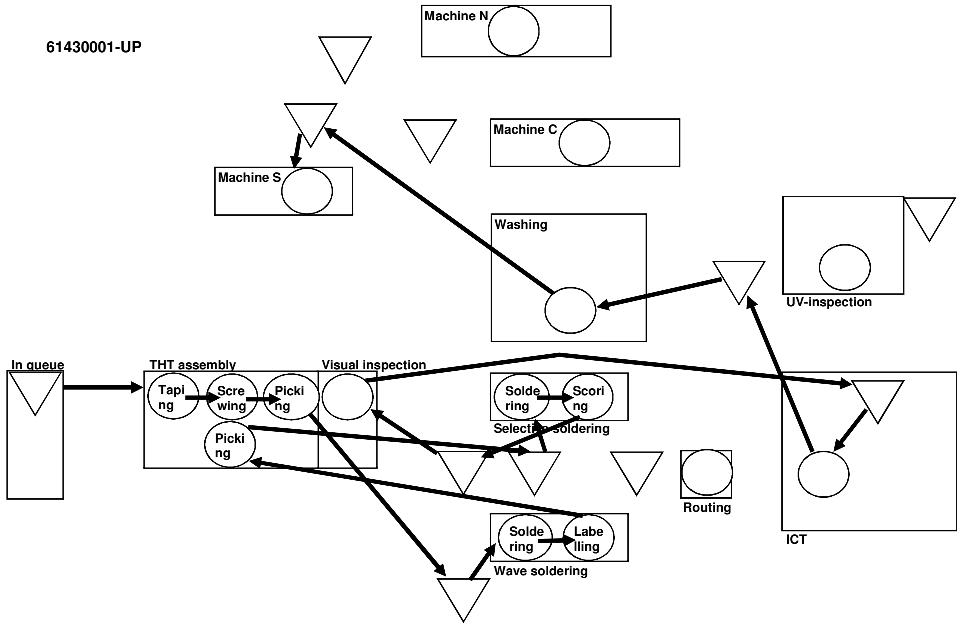
3EST000212-7864

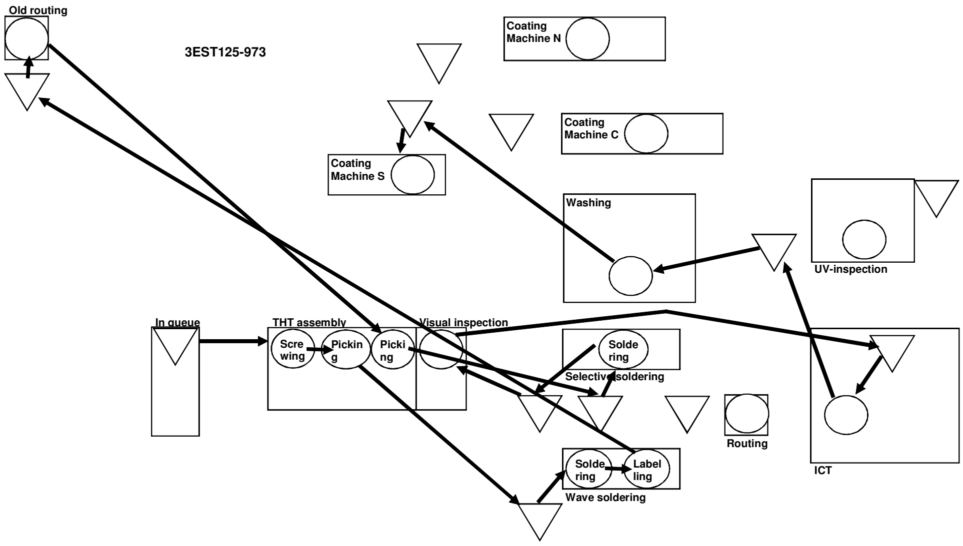


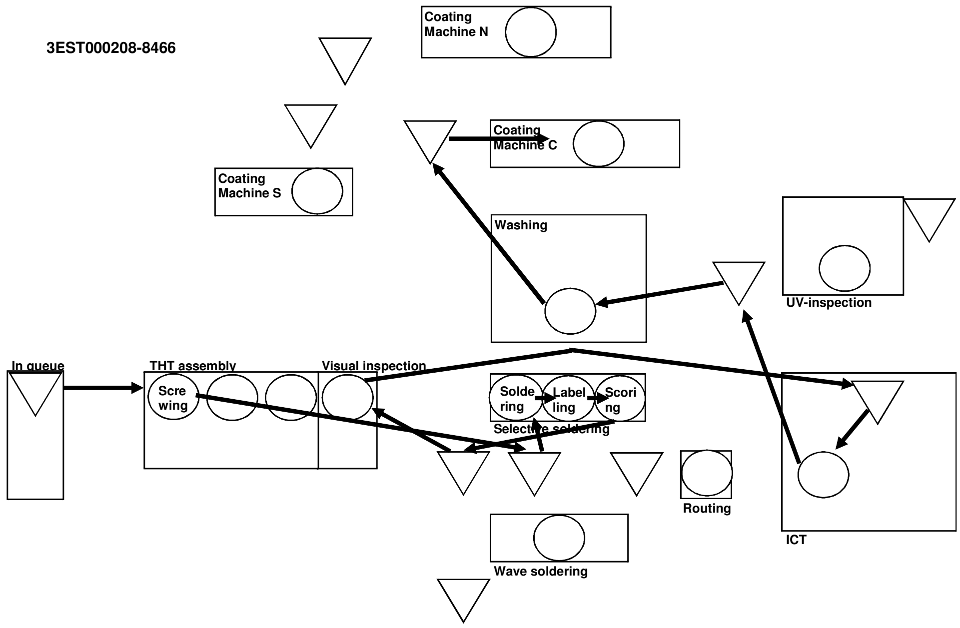
3EST000208-8476

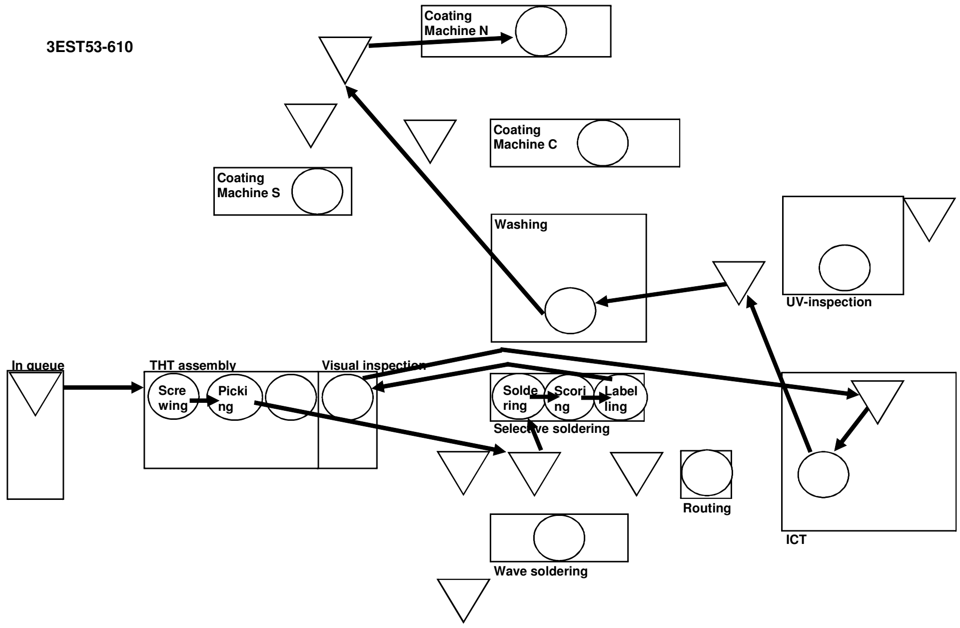


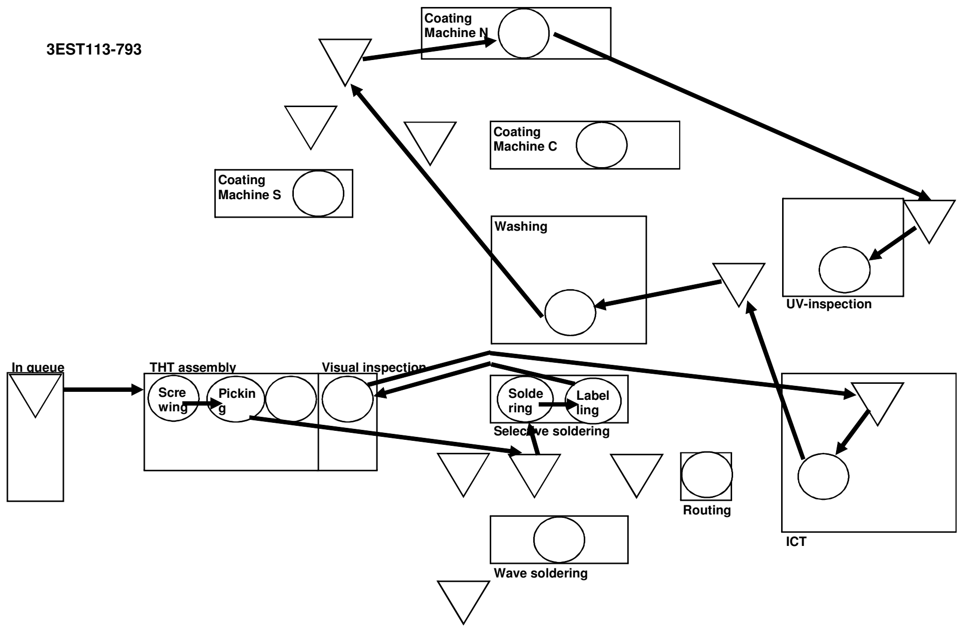
61430001-UP




Old routing
3EST125-973
Coating Machine N
Coating Machine C
Coating Machine S
Washing
UV-inspection
In queue
THT assembly
Visual inspection
Scre wing
Pickin g
Picki ng
Solde ring
Selective soldering
Routing
ICT
Solde ring
Label ling
Wave soldering


Coating Machine N
3EST000208-8466
Coating Machine C
Coating Machine S
Washing
UV-inspection
In queue
THT assembly
Visual inspection
Scre wing
Solde ring
Label ling
Scori ng
Selective soldering
Routing
ICT
Wave soldering





Supplement 5 Spaghetti diagrams

Critical Path Processes

Metric	Value	UOM	90 Units Inventory	Screwing 2op	01 Units Inventory	Picking 1op	64 Units Inventory	Soldering 5op	10 Units Inventory	Visual inspection 1 op	129 Units Inventory	ICT 1 op	26 Units Inventory	Washing 1 op	65 Units Inventory	Conformal coating 1 op
Processing Time	482	Seconds		56		38		68	0	90	0	90	0	40	0	100
Value Add Time	392	Seconds		56		38		68	kontroll görs	0	kontroll	90		40		100
# Workers	7	Operators		1		1		1		1		1		1		1
Man Cycle Time	274	Seconds		56		38		60		90		30		0		0
Machine Cycle Time	208	Seconds		0		0		8		0		60		40		100
Yield		%		100%		100%		98%		100%		95%		100%		95%
Uptime		%		98%		98%		90%		100%				95%		95%
Change Over Time		Min		20		20		12		5		15		0		25
Cycle Time		Seconds		56,00		38,00		68,00	0,00	90,00		90,00		40,00		100,00
Working Shifts per station		Shifts		1 shifts		1 shifts		2 shifts		1 shifts		2 shifts		2 shifts		1 shifts
Distance Traveled - Within	50	Meters		0		0		10	0	10	0	10		10	0	10
Critical Path Totals																
Queue Time	1,21	wDays	0,282 Days		0,003 Days		0,20 Days		0,031 Days		0,404 Days		0,081 Days		0,204 Days	
Processing Time	482	Seconds		56		38		68		90		90		40		100
Value Stream Totals																
Total Lead Time	1,21	wDays	0,282 Days		0,003 Days		0,20 Days		0,031 Days		0,404 Days		0,081 Days		0,204 Days	
Total Process Time	482	Seconds		56		38		68		90		90		40		100
Total Value Add Time	392	Seconds		56		38		68				90		40		100
Value add Ratio (VA /LT)	0,644%															
Cycle Time	100	Seconds		56,00		38,00		68,00		90,00		90,00		40,00		100,00

Critical Path Processes

Metric	Value	UOM	664 Units Inventory	Screwing 1 Op	01 Units Inventory	Picking 1 Op	64 Units Inventory	Soldering Op	24 Units Inventory	Visual inspection Op	840 Units Inventory	ICT Op	32 Units Inventory	Washing Op	32 Units Inventory	Conformal coating Op	24 Units Inventory	UV inspection OP
Processing Time	650,75	Seconds		85		56		91		88		135		60		75		48
Value Add Time	650,75	Seconds		85		56		91		88		135		60		75		48
# Workers	10	Operators		1		1		1		1		1		1		1		1
Man Cycle Time	650,75	Seconds		85		56		91		88		135		60		75		48
Machine Cycle Time	0	Seconds		0		0		0		0		0		0		0		0
Yield		%		100%		100%		100%		100%		100%		100%		95%		100%
Uptime		%		60%		60%		95%		80%		90%		100%		90%		90%
Change Over Time		Min		20 min		Min		12 min		5 min		15 min		0 min		25 min		10 min
Cycle Time		Seconds		85		56,00		91,00		88,00		135,00		60,00		75,00		48,00
Working Shifts per station		Shifts		1 shifts		1 shifts		2 shifts		1 shifts		2 shifts		2 shifts		2 shifts		2 shifts
Distance Traveled - With	90	Meters		2		3		6		4		15		15		10		10
Value Stream Totals																		
Total Lead Time	13,07	wDays	5,163 Days		0,008 Days		0,498 Days		0,187 Days		6,532 Days		0,249 Days		0,249 Days		0,187 Days	
Total Process Time	650,75	Seconds		85		56		91		88		135		60		75		48
Total Value Add Time	650,75	Seconds		85		56		91		88		135		60		75		48
Value add Ratio (VA /LT	0,099%																	
Cycle Time	135	Seconds		85		56,00		91,00		88,00		135,00		60,00		75,00		48,00

Critical Path Processes

Metric	Value	UOM
Processing Time	909	Seconds
Value Add Time	909	Seconds
# Workers	10	Operators
Man Cycle Time	909	Seconds
Machine Cycle Time	0	Seconds
Yield		%
Uptime		%
Change Over Time		Min
Cycle Time		Seconds
Working Shifts per station		Shifts
Distance Traveled - Withi	87	Meters

	Screwing	Picking	Soldering	Routing	Picking	Soldering	Visual inspection	ICT	Washing	Conformal coating
Inventory (before process)	46 Units	01 Units	0 Units	04 Units	0 Units	06 Units	0 Units	06 Units	02 Units	0 Units
Operators	1 Op	1 Op	1 Op	1 Op	1 Op	1 Op	1 Op	1 OP	1 Op	
Processing Time	195	234	29	100	0	58	137	60	96	0
Value Add Time	195	234	29	100	0	58	137	60	96	0
# Workers	1	1	1	1	1	1	1	1	1	0
Man Cycle Time	195	234	29	100	0	58	137	60	96	0
Machine Cycle Time	0	0	0	0	0	0	0	0	0	0
Yield	100%	100%	100%	100%	100%	100%	100%	95%	100%	100%
Uptime	60%	60%	100%	100%	60%	90%	80%	90%	100%	100%
Change Over Time	20 min	20 Min	5 min	0 min	10 min	12 min	0 min	0 min	0 min	0 min
Cycle Time	195	234,00	29,00	100,00	0,00	58,00	137,00	60,00	96,00	0,00
Working Shifts per station	1 shifts	1 shifts	1 shifts	1 shifts	1 shifts	2 shifts	1 shifts	2 shifts	2 shifts	2 shifts
Distance Traveled	3	3	10	5	15	10	6	20	10	0

Value Stream Totals		
Total Lead Time	12,78	wDays
Total Process Time	909	Seconds
Total Value Add Time	909	Seconds
Value add Ratio (VA /LT)	0,141%	
Cycle Time	234	Seconds

	Screwing	Picking	Soldering	Routing	Picking	Soldering	Visual inspection	ICT	Washing	Conformal coating
Inventory days	8,519 Days	0,185 Days	0,00 Days	0,741 Days	0,00 Days	1,111 Days	0,00 Days	1,111 Days	0,37 Days	0,00 Days
Process time	195	234	29	100		58	137	60	96	
Value add time	195	234	29	100		58	137	60	96	
Cycle time	195	234,00	29,00	100,00	0,00	58,00	137,00	60,00	96,00	0,00

Critical Path Processes

Metric	Value	UOM
Processing Time	1286,75	Seconds
Value Add Time	1286,75	Seconds
# Workers	10	Operators
Man Cycle Time	1286,75	Seconds
Machine Cycle Time	0	Seconds
Yield		%
Uptime		%
Change Over Time		Min
Cycle Time		Seconds
Working Shifts per station		Shifts
Distance Traveled - Withi	79	Meters

	Taping	Screwing	Picking	Soldering	Visual inspection	ICT	Washing	Conformal coating	UV inspection
Inventory (before process)	Inventory	Inventor	Inventor	Inventor	Inventor	Inventor	Inventor	Inventor	Inventor
Operators	Op	Op	Op	Op	Op	Op	Op	OP	1 Op
Processing Time	308	480	305	39	0	0	0	0	142
Value Add Time	308	480	305	39	0	0	0	0	142
# Workers	1	1	1	1	1	1	1	1	1
Man Cycle Time	308	480	305	39	0	0	0	0	142
Machine Cycle Time	0	0	0	0	0	0	0	0	0
Yield	100%	100%	100%	100%	100%	100%	100%	95%	100%
Uptime	60%	60%	60%	100%	60%	100%	100%	90%	100%
Change Over Time	20 min	20 Min	20 min	5 min	5 min	15 min	0 min	20 min	5 min
Cycle Time	308	480,00	305,00	39,00	0,00	0,00	0,00	0,00	142,00
Working Shifts per station	1 shifts	1 shifts	1 shifts	1 shifts	1 shifts	2 shifts	2 shifts	2 shifts	2 shifts
Distance Traveled	3	1	5	10	15	20	10	5	10

Value Stream Totals		
Total Lead Time	0,00	wDays
Total Process Time	1286,75	Seconds
Total Value Add Time	1286,75	Seconds
Value add Ratio (VA /LT)	#DIV/0!	
Cycle Time	480	Seconds

	Taping	Screwing	Picking	Soldering	Visual inspection	ICT	Washing	Conformal coating	UV inspection
Inventory days	0,00 Days	0,00 Days	0,00 Days	0,00 Days	0,00 Days	0,00 Days	0,00 Days	0,00 Days	0,00 Days
Process time	308	480	305	39					142
Value add time	308	480	305	39					142
Cycle time	308	480,00	305,00	39,00	0,00	0,00	0,00	0,00	142,00

Critical Path Processes

Metric	Value	UOM		Taping		Screwing		Picking		Soldering		Visual inspection		ICT		Washing			Conformal coating		UV inspection
			Inventory	Op	Inventor	Op	Inventor	Op	Inventor	Op	Inventor	Op	Inventor	Op	Inventor	Op		Inventor	OP	Inventor	1 Op
Processing Time	407,75	Seconds		0		0		0		39		0		130		129			0		97
Value Add Time	407,75	Seconds		0		0		0		39		0		130		129	kontr?		0		97
# Workers	10	Operators		1		1		1		1		1		1		1			1		1
Man Cycle Time	307,75	Seconds		0		0		0		39		0		30		129	kontr?		0		97
Machine Cycle Time	100	Seconds		0		0		0		0		0		100		0			0		0
Yield		%		0%		100%		100%		100%		100%		100%		100%			95%		100%
Uptime		%		0%		100%		100%		100%		100%		100%		100%			90%		100%
Change Over Time		Min		20 min		20 Min		20 min		5 min		5 min		15 min		0 min			20 min		5 min
Cycle Time		Seconds		0		0,00		0,00		39,00		0,00		130,00		129,00			0,00		97,00
Working Shifts per station		Shifts		1 shifts		1 shifts		1 shifts		1 shifts		1 shifts		2 shifts		2 shifts			2 shifts		2 shifts
Distance Traveled - Wi	80	Meters		4		1		5		10		15		20		10			5		10

Value Stream Totals																		
Total Lead Time	0,00	wDays	0,00 Days		0,00 Days		0,00 Days		0,00 Days		0,00 Days		0,00 Days		0,00 Days		0,00 Days		0,00 Days	
Total Process Time	407,75	Seconds								39				130		129				97
Total Value Add Tim	407,75	Seconds								39				130		129				97
Value add Ratio (VA /L	#DIV/0!																			
Cycle Time	130	Seconds		0		0,00		0,00		39,00		0,00		130,00		129,00		0,00		97,00

Critical Path Processes

Metric	Value	UOM	0 Units	Screwing	0 Units	Picking	12 Units	Soldering	0 Units	Visual inspectin	46 Units	ICT	12 Units	Washing	0 Units	Conformal coating
			Inventory	Op	Inventory	Op	Inventory	Op	Inventory	Op	Inventory	Op	Inventory	Op	Inventory	Op
Processing Time	438,75	Seconds		44		38		42		85		90		45		80
Value Add Time	438,75	Seconds		44		38		42		85		90		45		80
# Workers	9	Operators		1		1		1		1		1		1		1
Man Cycle Time	408,75	Seconds		44		38		42		85		60		45		80
Machine Cycle Time	30	Seconds		0		0		0		0		30		0		0
Yield		%		100%		100%		100%		100%		100%		100%		100%
Uptime		%		60%		60%		100%		60%		100%		100%		100%
Change Over Time		Min		20 min		20 Min		12 min		5 min		15 min		0 min		25 min
Cycle Time		Seconds		44		38,00		42,00		85,00		90,00		45,00		80,00
Working Shifts per station		Shifts		1 shifts		1 shifts		2 shifts		1 shifts		2 shifts		2 shifts		2 shifts
Distance Traveled - Within	73	Meters		3		4		5		6		15		10		5

Value Stream Totals																
Total Lead Time	0,92	wDays	0,00 Days		0,00 Days		0,157 Days		0,00 Days		0,604 Days		0,157 Days		0,00 Days	
Total Process Time	438,75	Seconds		44		38		42		85		90		45		80
Total Value Add Time	438,75	Seconds		44		38		42		85		90		45		80
Value add Ratio (VA /LT)	0,948%															
Cycle Time	90	Seconds		44		38,00		42,00		85,00		90,00		45,00		80,00

Critical Path Processes

Metric	Value	UOM
Processing Time	436,75	Seconds
Value Add Time	436,75	Seconds
# Workers	9	Operators
Man Cycle Time	436,75	Seconds
Machine Cycle Time	0	Seconds
Yield		%
Uptime		%
Change Over Time		Min
Cycle Time		Seconds
Working Shifts per station		Shifts
Distance Traveled - Withir	87	Meters

Value Stream Totals		
Total Lead Time	1,20	wDays
Total Process Time	436,75	Seconds
Total Value Add Time	436,75	Seconds
Value add Ratio (VA /LT)	0,720%	
Cycle Time	95	Seconds

	Screwing	Picking	Scoring	ICT	Washing	Conformal coating	Routing
Inventory	23 Units	01 Units	28 Units	80 Units	51 Units	17 Units	29 Units
	1 Op	1 op	1 Op	1 Op	1 Op	1 Op	1 Op
Processing Time	56	95	8	78	65	80	40
Value Add Time	56	95	8	78	65	80	40
# Workers	1	1	1	1	1	1	1
Man Cycle Time	56	95	8	78	65	80	40
Machine Cycle Time	0	0	0	0	0	0	0
Yield	100%	100%	100%	100%	100%	100%	100%
Uptime	60%	60%	100%	100%	100%	100%	100%
Change Over Time	20 min	20 Min	5 min	15 min	0 min	25 min	5 min
Cycle Time	56	95,00	8,00	78,00	65,00	80,00	40,00
Working Shifts per station	1 shifts	1 shifts	1 shifts	2 shifts	2 shifts	2 shifts	1 shifts
Distance Traveled	5	5	15	7	10	5	15
Days	0,12 Days	0,005 Days	0,147 Days	0,42 Days	0,27 Days	0,09 Days	0,152 Days
	56	95	8	78	65	80	40
	56	95	8	78	65	80	40
	56	95,00	8,00	78,00	65,00	80,00	40,00

Critical Path Processes

Metric	Value	UOM
Processing Time	420,75	Seconds
Value Add Time	420,75	Seconds
# Workers	10	Operators
Man Cycle Time	420,75	Seconds
Machine Cycle Time	0	Seconds
Yield		%
Uptime		%
Change Over Time		Min
Cycle Time		Seconds
Working Shifts per station		Shifts
Distance Traveled - Wit	75	Meters

Value Stream Totals		
Total Lead Time	11,55	wDays
Total Process Time	420,75	Seconds
Total Value Add Time	420,75	Seconds
Value add Ratio (VA /LT	0,072%	
Cycle Time	162	Seconds

	Screwing	Picking	Soldering	Picking	Soldering	Visual inspection	ICT	Washing	Conformal coating
Inventory	103 Units	01 Units	04 Units	0 Units	17 Units	0 Units	32 Units	09 Units	0 Units
	Op	Op	Op	Op	Op	Op	Op	OP	1 Op
Processing Time	0	116	20	0	45	162	35	30	0
Value Add Time	0	116	20	0	45	162	35	30	0
# Workers	1	1	1	1	1	1	1	1	1
Man Cycle Time	0	116	20	0	45	162	35	30	0
Machine Cycle Time	0	0	0	0	0	0	0	0	0
Yield	100%	100%	100%	100%	100%	100%	100%	95%	100%
Uptime	60%	60%	100%	100%	100%	100%	100%	90%	100%
Change Over Time	20 min	20 Min	5 min	10 min	12 min	5 min	15 min	0 min	10 min
Cycle Time	0	116,00	20,00	0,00	45,00	162,00	35,00	30,00	0,00
Working Shifts per station	1 shifts	1 shifts	1 shifts	1 shifts	2 shifts	1 shifts	2 shifts	2 shifts	2 shifts
Distance Traveled	5	5	10	10	10	5	15	10	5
Days	7,153 Days	0,069 Days	0,299 Days	0,00 Days	1,188 Days	0,00 Days	2,243 Days	0,597 Days	0,00 Days
		116	20		45	162	35	30	
		116	20		45	162	35	30	
	0	116,00	20,00	0,00	45,00	162,00	35,00	30,00	0,00

Supplement 6 Value stream maps

Product	*Demand/year*	*Demand/week*	*Processing time(s)*	*Processing time/week(h)*	*Panel X (mm)*	*Panel Y (mm)*
3EST113-793	20019	476,6	92,54	12,25	180	216
3EST53-610	18351	436,9	65,18	7,91	207,5	248
3EST000209-3794	4700	111,9	215,36	6,69	297	309
3EST000208-8466	20000	476,2	42,83	5,67	94,8	351
3EST000214-1776	8000	190,5	98,13	5,19	170	283
3EST000211-8565	7955	189,4	82,26	4,33	170	283
3EST000211-7953	5000	119,0	104,12	3,44	170	293
3EST000209-3763	4700	111,9	103,27	3,21	135	309

Supplement 7 Second selection of products

Product								
3EST113-793 DYTP150A C/T	Assembly 1 169	Assembly 2 113	Selective soldering 93	Labelling	Visual inspection	Breaking panel	ICT LMBDM 65	
3EST53-610 DYTP140A C/T	Assembly 1 99	Assembly 2 136	Selective soldering 65	Scoring	Labelling	Visual inspection	ICT FFV 96	
3EST000209-3794 DTCC751B C/T	Assembly 1	Assembly 2	Selective soldering 215	Scoring	Labelling	Visual inspection	Washing ICT 70	
3EST000208-8466 DTCA751A C/T	Assembly 1 44	Assembly 2 38	Selective soldering 43	Scoring	Labelling	Visual inspection	ICT LMBDM 110	
3EST000214-1776 DYTP151D C/T	Assembly 1	Assembly 2	Selective soldering 98	Scoring	Labelling	Assembly 3	Visual inspection	ICT LMBDM 205
3EST000211-8565 DYTP151B C/T	Assembly 1	Assembly 2	Selective soldering 82	Scoring	Labelling	Visual inspection	ICT LMBDM 45	
3EST000211-7953 DYTP 151A C/T	Assembly 1	Assembly 2	Selective soldering 104	Scoring	Labelling	Visual inspection	ICT 43	
3EST000209-3763 DTEX 752A C/T		Assembly 1	Selective soldering 103	Scoring	Labelling	Visual inspection	ICT 70	

Supplement 8 Selected products and operations with known cycle times