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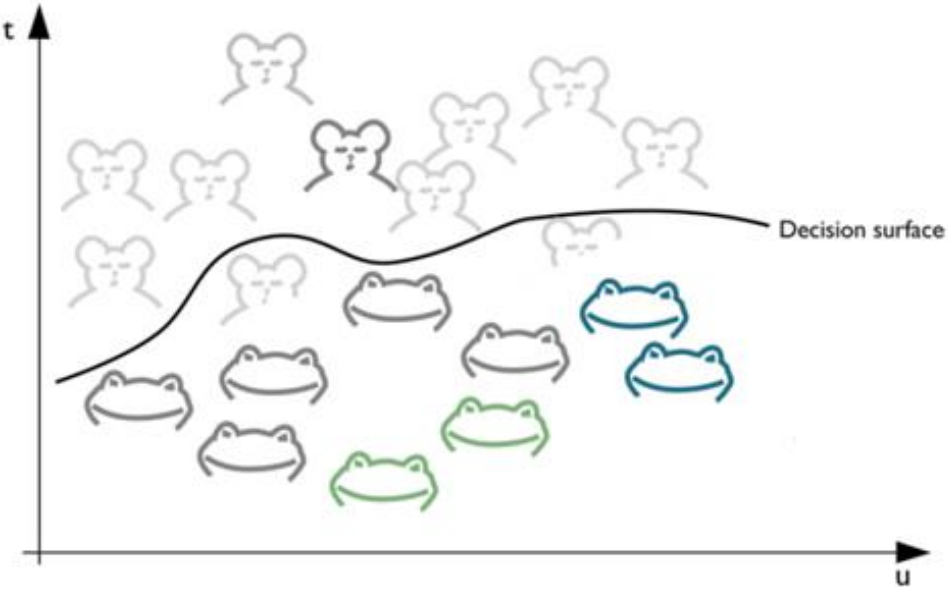

Definition and Visualisation of Statistical Data from a Monitoring and Inspection System

Development of an interface that presents statistical data from a Machine Vision System in a Production unit

Master of Science Thesis in the Master Degree programmes, Production Engineering and System, Control and Mechatronics

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Cover: An illustration of how the classification algorithm *Manto* performs quality assurance. Further explained in sub-chapter *1.3 Consat Quidance Vision.*

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This report, *Definition and Visualisation of Statistical Data from a Monitoring and Inspection System*, is written as a master thesis by two students from the master degree programmes *Production Engineering* and *System, Control and Mechatronics* at Chalmers University of Technology. The project was issued by Consat Engineering AB located in Partille, Sweden.

The project is intended to improve an existing Machine Vision System developed by Consat Engineering AB. Both by recommendations on areas of improvements as well as enhance the interface of the Machine Vision System. Further, the report presents an example of how to visualise production statistics in the interface.

First, the authors specially want to thank our examiner and supervisor Cecilia Berlin, assistant professor at Chalmers University of Technology, for her enthusiasm and dedication for this thesis.

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Abstract

Automated production lines are commonly seen in Swedish industries to provide the customer with low prices and short delivery times. However the speed of the automated production lines demands the quality control to not only be repeatable and accurate but also to be fast. There are various options available to automatically ensure quality today. One alternative is Machine Vision System which could be used to quickly ensure quality of the process or product.

The purpose of this project was to investigate development potentials for an existing Machine Vision System. The system could be compared to the human eye and brain that has the complexity to recognize patterns and deviation. The Machine Vision System developed by Consat Engineering AB was mainly used for quality control, inspection and robot positioning.

The project focused on how production statistics could be visualised in the Machine Vision System´s interface. The methods used in order to collect data were observations and interviews with participants from three companies. The development of the final result focused on visualisation of production statistics at one of the companies.

The result of this project was a concept model that presented how production statistics could be visualised and a list with development potentials based on data from interviews and observations.

Keywords: production statistics, statistical process control, SPC, snowball recruitment, interviews, observations, data collection, concept model, interface, machine vision, monitoring system.

Nomenclature

Beneficiaries	Identified users of the concept model
Concept model	Visualisation of statistical data integrated in Consat Quidance Vision interface
Consat	Consat Engineering AB
CQV	Consat Quidance Vision
DMAIC	Define-Measure-Analyse-Improve-Control, improvement methodology in Six Sigma projects
DPMO	Defect part per million opportunities
HTML	HyperText Markup Language
MVS	Machine Vision System
PLC	Programmable Logic Controller
Process	The machine, and hardware, that holds the process of producing a product
SIPOC	Suppliers, Inputs, Process, Outputs and Customers
Stakeholder	Representative affected by a development of the CQV interface
Statement	Expression from the participants in the interviews and observations
PDCA	Plan-Do-Check-Act a four step method for control and continuous improvements within an organization

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1. Introduction

Automation today is commonly seen in Swedish industries. A common system used to ensure repetitive quality inspection is machine vision. Machine vision can control a process and at the same time supply the user with a lot of data in a short period of time (USTECH, 2013).

The increased passion for collecting parameters in Swedish companies seems to be a part of the future, hand in hand as the technology develops. Today´s society is all the time logging and saving data in order to map and predict trends and events, as the outbreak of a flu or equalise the utilisation of the wireless phone lines (Vetenskapens värld, 2014). But collecting data not only mean that the ability to find trends and patterns emerge, the use of statistical tools are necessary in order to handle large quantities of data.

1.1. Background

This project was conducted by two students from Chalmers University of Technology within the master programmes of *Production Engineering* and *System, Control and Mechatronics.* The project was issued by Consat Engineering AB, an engineering agency located in Partille, Sweden.

The purpose was to deliver a foundation for further development of an existing Machine Vision System (MVS) developed by Consat. The MVS goes by the name *Consat Quidance Vision* (CQV) and was installed at various industries in Sweden, mainly used for quality control, inspection and robot positioning. The goal with this project was to find improvement potentials for the CQV and to present a concept to visualise production statistics in the CQV interface.

This project emerged due to customers' interest in further development of the CQV interface. One customer, that at the time was using CQV for quality inspection at their production unit, had expressed that they would be interested in developing the CQV interface for usability and presentation of production statistics. The focus was to determine if production statistics was of interest and how this would be presented in the CQV interface. The standard view of the interface found at the company is presented in *figure 1-1*.

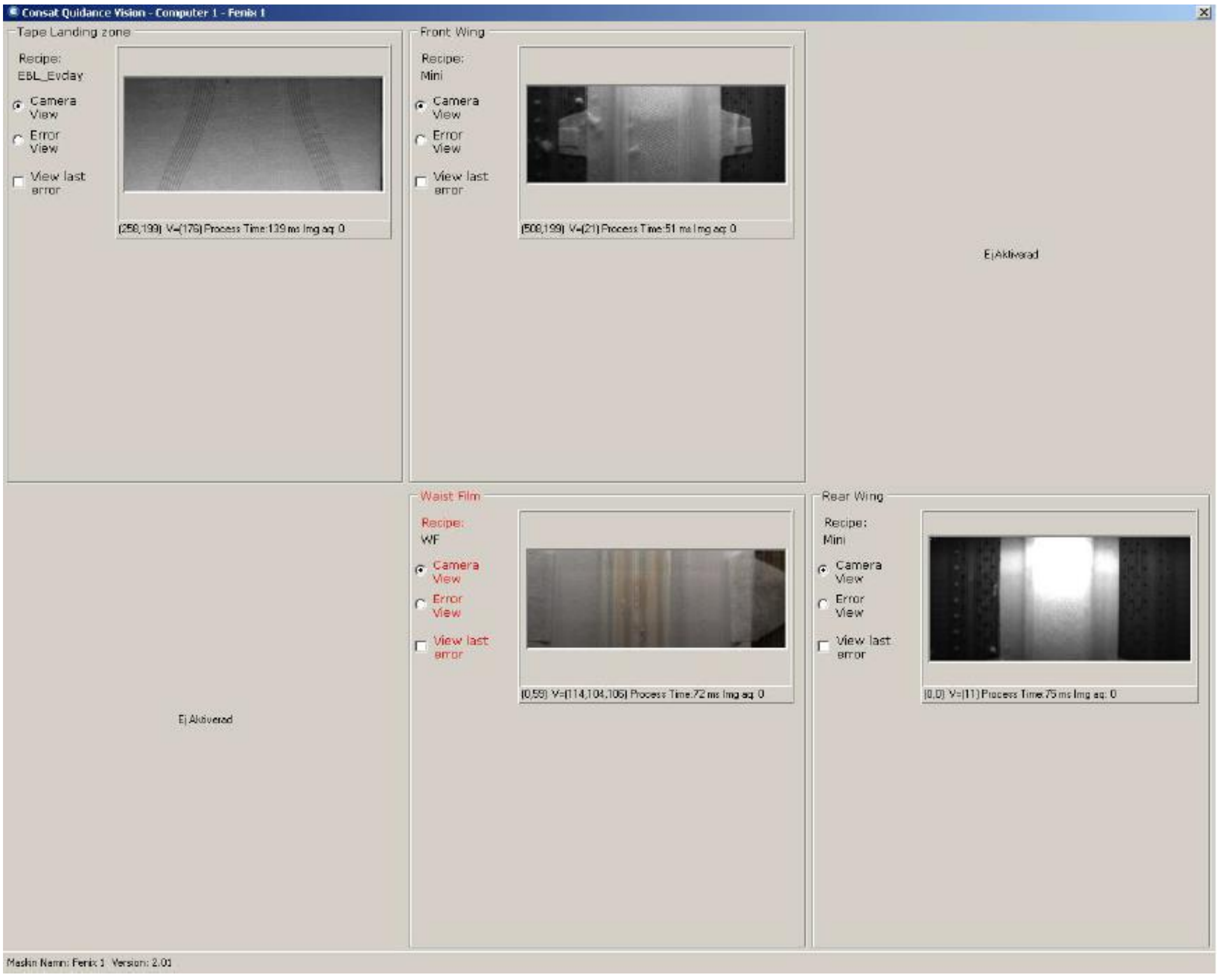

Figure 1-1 The standard view in the current CQV interface (Consat, 2014a).

Two other customers were also of interest to investigate in this project due to their interest in developing the CQV platform.

A requirement from Brandt (2014) and Svensson. A (2014) was that the developed interface should have the same general appearance as the current CQV interface, see *figure 1-1*. Consat wanted the project to determine potential development areas for their MVS as well as present one example of a developed interface based on opinions found at one customer. The representatives from the companies were predefined by Consat. All three companies were manufacturing companies with production units located in Sweden.

1.2. Machine Vision

Machine vision is a technology which can replace or work as a complement to manual measurement. A MVS operates with inputs from sensors and cameras, *figure 1-2*, and delivers a result based on predefined limits. This technology can be found in many different areas such as parking assistance in a car or surveillance system in a shopping mall. The goal of using machine vision in a production unit is to improve the throughput and yield but also to ensure product quality (Sick IVP, 2006).

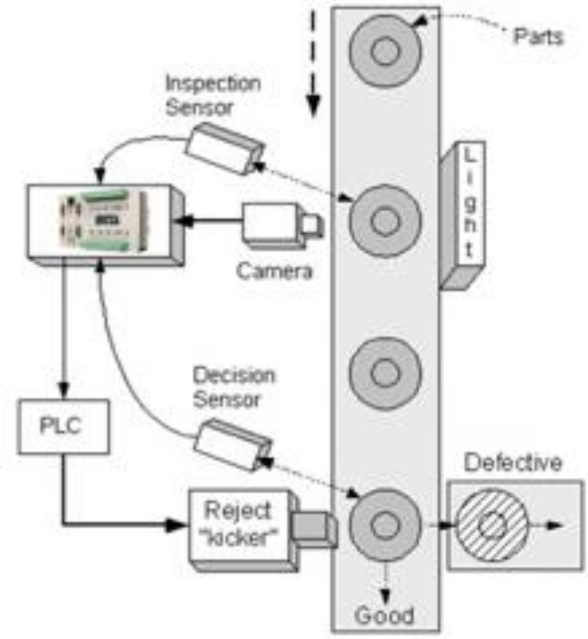

Figure 1-2 General solution of a production line using machine vision (USTECH, 2013).

A conventional MVS operates with 2D images but a variety of other applications exists. 3D images can be established with a 2D image together with measurements of the object, conventionally performed by laser (Sick IVT, 2006).

Commonly white light is used to illuminate the object but it exist applications were white light is not sufficient. Detection of adhesives could be illuminated with is one application where white light preferably could be replaced by UV light that highlights the adhesives (Johansson, 2014).

Machine vision can operate with a variety of algorithms. Counting pixels (measure), digital filters (highlight a specific part), edge finding, blob analysis (measure centroid, area, length and orientation of an object) and pattern matching (comparison of objects) are a few that are commonly used for image processing (Sick IVP, 2006).

Outputs from the MVS could be sent to a picking robot, a PLC or other types of systems. The output to a picking robot could be coordinates which tells the robot where to operate, this can be referred as guidance. The output could also be information about a non-approved product and used as a quality assurance in a production line, this is referred as quality (Sick IVP, 2006).

Fabel (1997) presents the reason to why machine vision has become popular in production units are because quality inspection is repetitive and requires accurate measurement. A monitoring system can handle big amount of data in a short period of time and performs decisions based on equal criteria every time. A MVS can not only contribute to adequate decisions it can also detect what is impossible for the human eye, referring to infrared light, x-ray and magnetism (Fabel, 1997).

1.3. Consat Quidance Vision

Consat has developed a flexible MVS called Consat Quidance Vision (CQV). The word *Quidance* can be read out as Quality and Guidance. CQV is a fully scalable platform that in the manner of desire allows different tasks and tools to be combined and offers a platform with almost unlimited possibilities according to Brandt (2014). Application areas for the CQV platform are mainly quality control, inspection and robot positioning. With quality inspection both classification and measurement application can be covered, and combined quality inspection and robot positioning can be used for increased functionality (Consat, 2014a).

The hardware of CQV is in general a computer, a grayscale and/or a colour camera, light panels, network adapter and a display, illustrated in *figure 1-3*. The cameras are triggered with a trigger signal from a PLC when the product is passing the cameras. If the image is classified as “not ok” the vision system will send an error signal to the PLC which allows it to track the defect products and remove them from the production process (Consat, 2014a).

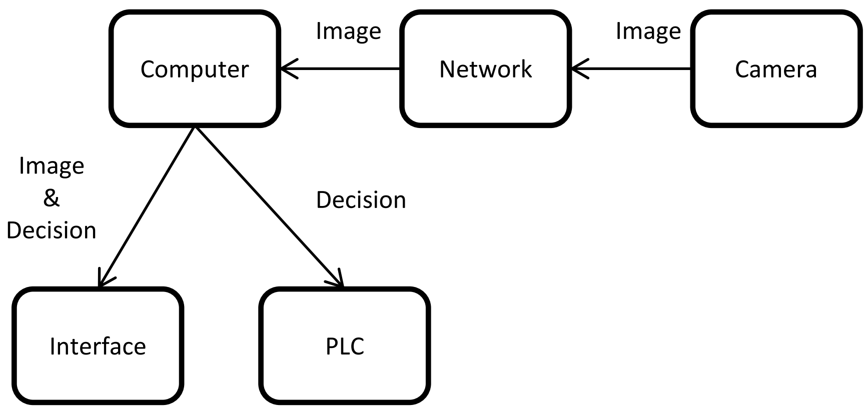

Figure 1-3 General schedule of CQV

CQV is installed at a number of clients in different type of industries where both robot positioning and quality inspection were in use. CQV has the ability save images of defect products to enable optimization of the production unit. Furthermore, CQV has a standard user interface that provides the user with information from the process, and offers the user to control and adjust production process to some extent (Consat, 2014a).

CQV commonly operates with an algorithm called *Manto.* This algorithm uses reference images to decide whether a product is correct or not. This can be compared to manual inspection comparing one product to already approved products. *Figure 1-4* illustrates how *Manto* can detect “ok bears” and “not ok bears”. Below the decision surface are bears that are similar to the “ok” bears but sorted out due to the fact that they are incomplete (Consat, 2014a).

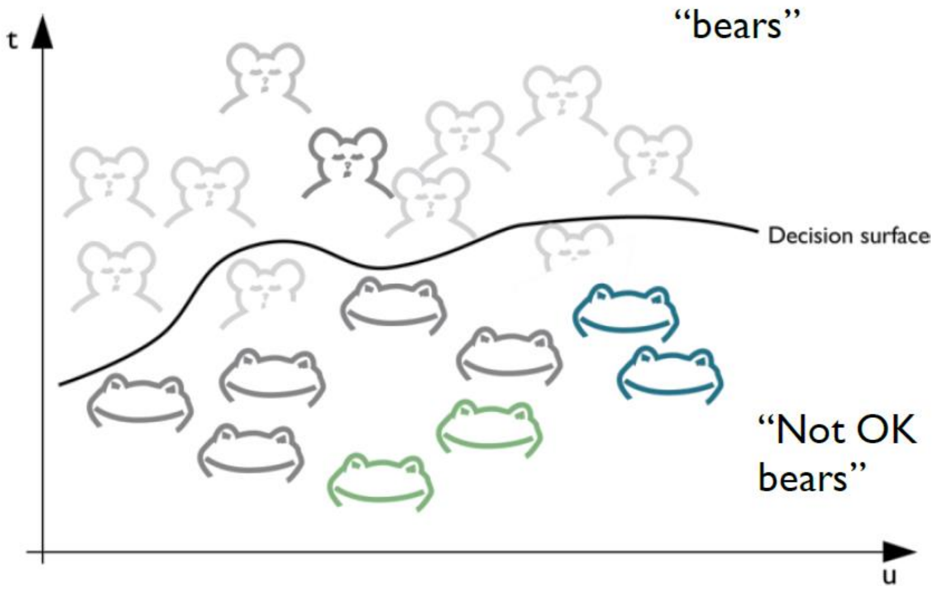

Figure 1-4 *Manto* classifies “ok” and “not ok” products (Consat, 2014a).

CQV was designed to handle several algorithms. One other algorithm used besides *Manto* is *Blob detection*. The *Blob* algorithm delivers information of an image which makes it possible to calculate length, area, location and orientation of an object (Consat, 2014a). Example of this is presented in *figure 1-5* where *Blob* has been used for calculate picking points for 5 products.

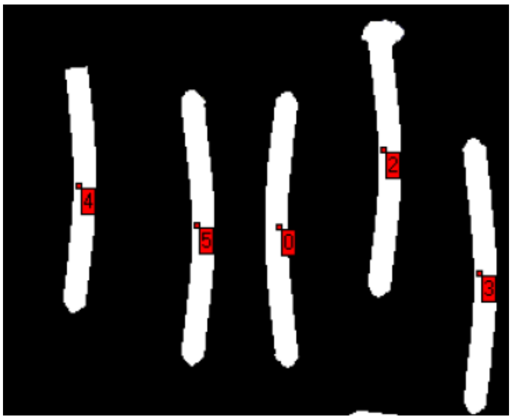

Figure 1-5 ***Blob*** **has calculated picking points, marked with red dots (Consat, 2014a).**

When the system has processed an image, with *Manto* and/or the *Blob detection* algorithm, the system presents the output in the CQV. The CQV interface presents the last captured image. If a “not ok” product is found the image of the product will be shown in the *View last error*, see *figure 1-6*. The image will be saved and an error history is available even after the error occurred (Consat, 2014a).

Figure 1-6 Interface of ***camera view*** **and the** ***last error view*** **in CQV (Consat, 2014a).**

The *error view* presents stored images in a chronologic list, *figure 1-7*. This provides the user with an overview of recent production problems.

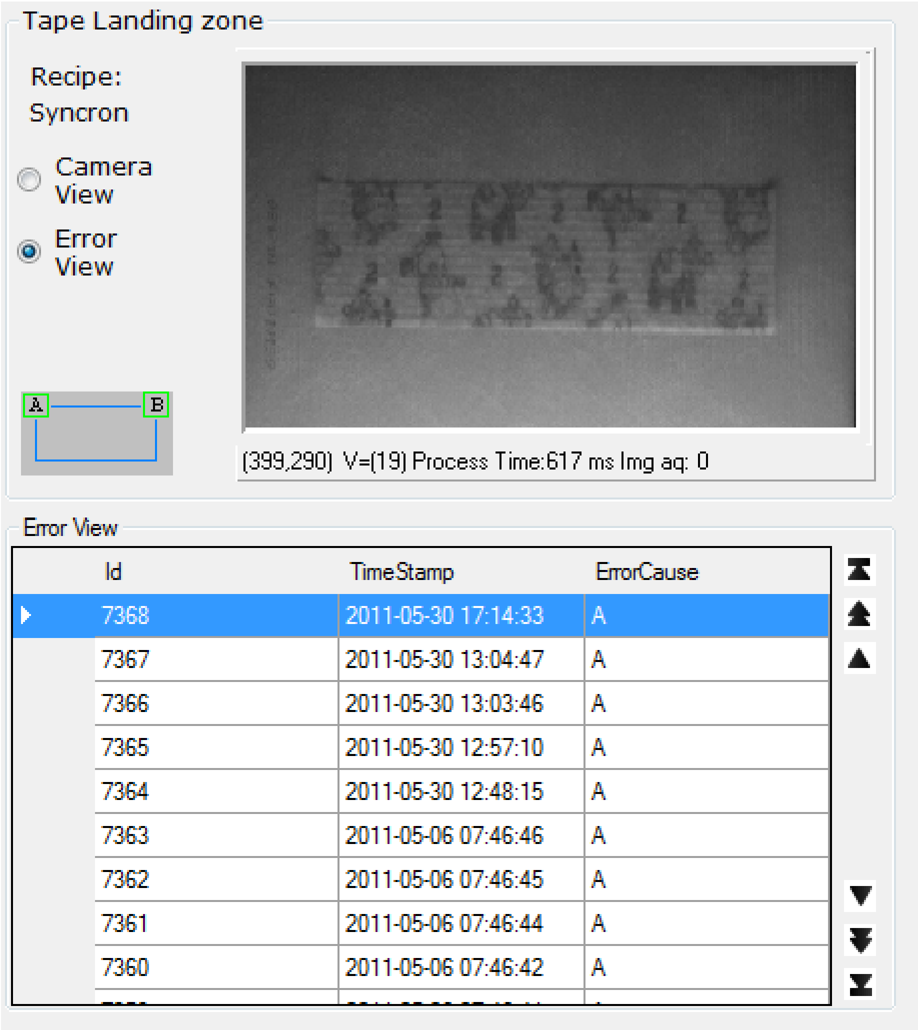

Figure 1-7 *Error view* with a chronological list.

2. Project definition

This chapter aims to clarify the projects purpose and goal. The customer that expressed interest in developing the CQV interface was visited at the beginning of this project. The visit represents a pre-study with the purpose to enhance details and depth regarding the CQV system installed at the customer’s production unit. This customer will further be mentioned as Company A. Supplied perception from the pre-study contributed to the development of the template used for interviews conducted at the same company, presented in *chapter 5*.

The goal of the pre-study was to explore the CQV at Company A by investigate the following topics:

- *The stakeholders*
- *Significant information related to the industry, precision and quality regarding their process and product*
- *Where machine vision could be found*
- *Commonly used production statistics*

2.1. Pre-study

Company A was a manufacturing company located in Sweden. At the plant seven automated production lines were installed operating 24/7 except for special holidays. Each production line had three operators in each of their five shifts. The production lines had the capacity of producing between 500 and 1200 products every minute.

The final product consisted of a number of raw materials that was merged together in the production process. At the end of the process the products were packed into plastic bags and cartons and stored in their local warehouse. The process was almost fully automated except for the raw material supply which was handled manually by the operators. At various places in the process were cameras, connected to the CQV, installed to perform quality inspection directly when the raw material was merged onto the product. The CQV´s purpose was to decide with the *Manto* algorithm (*Manto* is explained in *1.3 CQV*) about the condition of the product directly in the CQV interface and the operator panel.

If CQV detected a deviation in quality a notification was sent to both CQV interface and to the operators’ panel, both screens were located close to the production unit. The operator panel was the main screen used by the operators to find information regarding the production unit, where also alarms detected by the CQV were presented. If an error was presented in the operator panel, the operators could decide whether to stop the production and try to find the cause or ignore the notification. Major errors forced the production process to automatically slow down or to shut down, to get the machine up and running again the operators needed to find the cause of the error and restore it manually.

The operators were responsible to perform manually tests every 15 minute on four complete products, tensile and strain testing, to ensure quality. Test necessary to perform due to the fact that current quality system was not used to detect those parameters. These results were sent to another department, the quality department. A drawback with the manually performed tests was that it left the product incomplete which made it impossible to redo the test.

The pre-study involved a meeting and a supervised tour at the production plant with the determined representative, a process engineer, referred as P2 (2014c). The process engineer was responsible for one of the production lines where the CQV was installed for quality inspection.

The process engineer provided the researchers with potential stakeholders for visualisation of production statistics in the CQV interface:

- Operators
- Quality department
- Process engineers
- Manager of the production unit

Commonly used production statistics were Six Sigma and statistical process control.

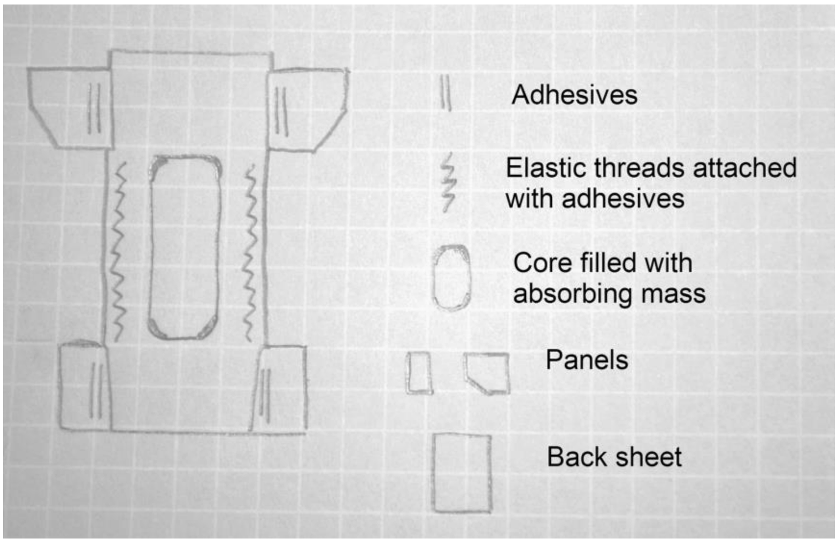

Figure 2-1 Illustration of the product produced by Company A.

The product consisted of one back sheet with four panels, two placed in the front and two in the back of the product, *figure 2-1*. A core filled with absorbing mass was mounted directly on the back sheet and along the sides were elastic threads attached with adhesives.
The adhesive process was controlled by a pump. The core mass was filled directly onto the back sheet of the product. The final products were then time stamped and packed in plastic bags in batches of 20. Last step was to pack an amount of plastics bags into a carton box. The time stamps were added on both the plastic bags and the cartons.

2.2. Purpose and Goal

The purpose and goal with this project was to deliver a foundation for future development projects of the CQV platform and to develop a concept model that presents how to visualise production statistics in the CQV interface.

2.3. Delimitations

This project contained qualitative and empirical studies at three manufacturing companies in Sweden. The visited companies were predetermined by Consat. Interviews were conducted at one company and the participants were recruited by company employees. The result of the interviews worked as a foundation for the development of the CQV interface. Observations were conducted at two companies. This project resulted in a foundation for future development project of the CQV based on data acquired from empirical studies at three companies. This report presents one concept that illustrates how production statistics could be visualised. This project excludes implementation and investigation of the delimitations of the CQV platform.

2.4. Problem definition

The pre-study defined that CQV had potential to be used in more areas and be adopted to benefit the user. The development of the current CQV was conducted without input from the users. The researchers aimed to find how the CQV could be developed by interviewing and observing companies that used CQV. This project resulted in a list with sorted statement based on the interviews and observations. Further this project presents a concept model that illustrates how to visualise production statistics in the CQV interface.

3. Methodology

This chapter presents the methodology used to fulfil the goals and the purpose of this project. This chapter includes methodology used for literature review, data collection, analysis and development of a concept model.

3.1. Research approach

The research was divided in two tracks, *figure 3-1*. The tracks were conducted in parallel through the project duration. The first track, literature review consists of theory regarding production statistics and how to design an interface. The purpose of the literature review was to gather a theoretical base for this project.

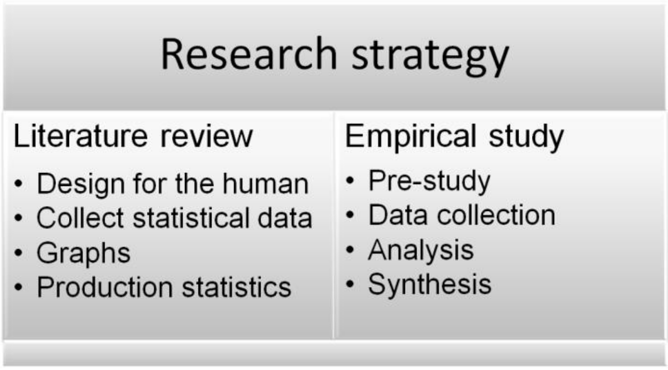

Figure 3-1 Research structure for this project

The empirical study was divided into five phases. The pre-study gathered material in order to design and conduct the data collection. The data collection consisted of two parts, interviews at Company A and observations at Company B and C. In the analysis were collected statements from the data collection sorted and mapped in order to find where visualisation of production statistics was expressed. The analysis included KJ analysis, function analysis and a development of specification of requirements. The concept model was developed from the specification of requirements with support from theory gathered in the literature review.

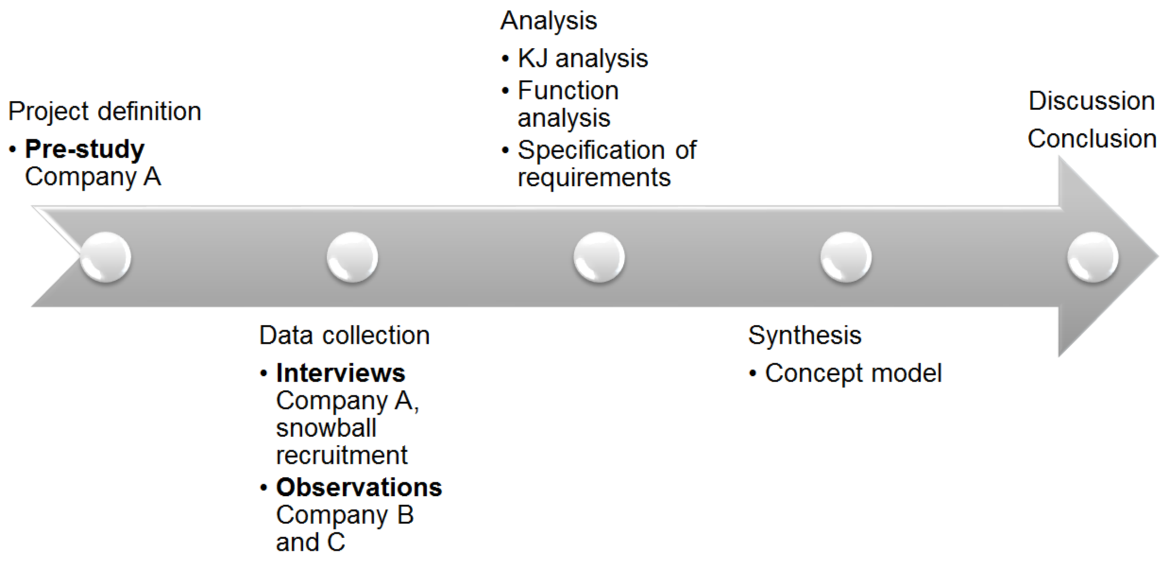

Figure 3-2 Research structure for the empirical study.

3.2. Data collection

The purpose with the data collection was to gather data from the three companies in order to develop a function list based on empirical studies. This section presents the methodology used to find requirements and needs from the predetermined participants from the three companies and from recruited interviewees at Company A.

The data collection included interviews conducted at one company and observations conducted at two companies. Interviews at Company A, observations at the two other companies further mentioned as Company B and Company C. The list of statements that was established contains statements from the interviews and the observations.

3.2.1. Snowball recruitment

To find participants for the interviews related to the production unit at Company A, snowball recruitment was used. The snowball recruitment method responds to that the determined representative at Company A recommended company employees for the interviews. Further, the employees were in their turn recommending other employees. Finally, the chosen participants for the interviews were employees related to the production unit at Company A, and also representatives from the identified departments from the pre-study. Snowball recruitment is time effective and simple but limits the researchers´ overall view of the distribution of the recruited stakeholders (Explorable, 2009).

The snowball recruitment method was useful to be able to find participants for the interviews within the time duration of this project. The participants should represent the identified departments from the pre-study and be connected to the production unit at Company A. It was not important that the interviewees were familiar with the CQV system due to the fact that the purpose was to find development potentials beyond the current CQV platform.

3.2.2. Qualitative data collection

Interviews are commonly performed in a structured, unstructured or semi-structured way (Berlin and Adams, 2014). This project includes semi-structured interviews.

The strategy was to have head questions and allow sub questions and additional topics to emerge during the interview session. During the sessions the interviewees' words were formulated and written down on paper. The data collection aims to find information expressed by the interviewees. The data collection was conducted with an interview template, the template can be found in *appendix A – Interview template*. The interview template contained questions aiming to investigate the following purposes:

- *Find general information regarding the interviewees' work tasks and background*
- *Detect how they work and possible obstacles in their daily work*
- *Find development potentials related to vision*
- *Find commonly used production statistics*
- *Find frequent problems*
- *Find out how information preferably can be presented*

The observations at Company B and C were conducted with a supervised tour at their production unit with the dedicated participants. During the observations information were gathered from what was visual in the production unit together with discussions and expressions from the representative. The data collections at Company B and C were not aiming to observe workers or processes, the aim was to enhance the perspective on how the companies worked with and potential future use of machine vision.

3.3. Analysis of the collected data

This sub-chapter presents how the analysis of the collected data was performed. The purpose of the analysis was to develop a function list and a specification of requirements for the development of a concept model.

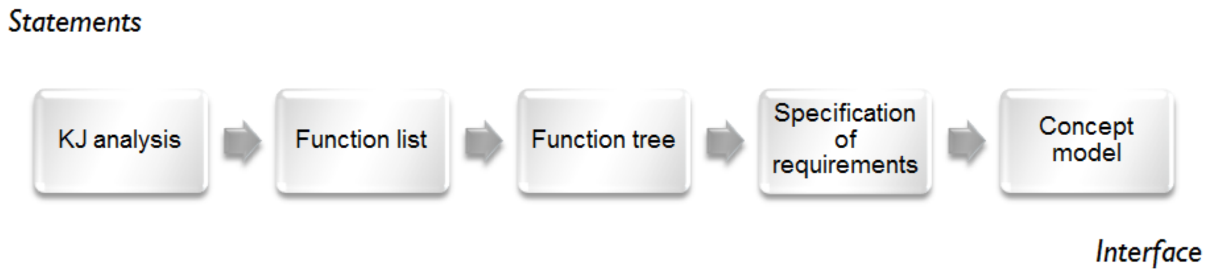

Figure 3-3 Structure of the analysis.

The KJ analysis resulted in a list of statements, further derived into functions and finally resulting in a specification of requirements used for the development of the concept model, *figure 3-3*.

3.3.1. KJ analysis

The KJ analysis was developed in the 1960´s by Kawakita Jiro, hence its name, which is used as a management and planning tool. The transformation of the notes from the interviews and observations into a sorted list was performed with a KJ analysis (also known as *the affinity method* or *post-it method*). The KJ analysis contributed to sort the statements and analyse the collected data. The goal was to write down one statement on a post-it and sort them into themes. Statements found in the data collection were handled individually. The advantage of using this method is that it starts with evaluating the statement and aims to find headlines and categories during the analysis session (Bligård, 2011).

Following methodology was used to perform the KJ analysis:

1. Statements were taken from the data collection, collected by interviews and observations
2. The statements were written down on post-it notes, one statement on each post-it
3. The post-it notes were randomly placed on a table
4. Both researchers were allowed to sort the post-it´s into groups by themes, after discussions one solution was established
5. The themes were named
6. Additional step, the step 4 was performed again. This step was useful in order to find master headers for some of the themes
7. The diagram was then complete. Master headers were named, discussed and the analysis was documented, *figure 3-4*.

Figure 3-4 Statements written on post-it´s grouped into themes with master header in the KJ analysis.

3.3.2. Function analysis

A goal with this project was to deliver a concept model of a CQV interface. To find functions that this system should contain a function analysis was made. A function analysis contributes to find what functions to have, but not how or why (Bligård, 2011). The function analysis was conducted with the results from the KJ analysis and contributed to the development of a specification of requirements.

Function list

The goal of the function analysis was to find what functions the concept model should include. The functions listed were termed with a verb, a noun and possibly a clarification (Johannesson et al, 2004). The functions were divided into main, necessary and wanted functions. This should show how important each function was and contribute to a development of a concept model based on the result from the data collection.

Function tree

A function tree was created to show the relations between the functions. This function tree graphically expressed the relations and connections between the functions. A movement upwards in the tree refers to why a function exist, while the movement downwards refers to how a function is satisfied (Bligård, 2011).

3.3.3. Specification of requirements

The function list was then derived into a specification of requirements, the foundation for the development of a concept model. A specification of requirements can contribute to that the established result fulfils the demands of a user (Bligård, 2011). The specification of requirements was presented in a list with one requirement on each row. Each requirement was presented with a clarification and a classification, expressing the importance of the fulfilment of the requirement. The classification was ranked with *Must, Necessary* and *Want* where *Must* represented the most important and *Want* the least important requirement to fulfil.

3.4. Synthesis

A concept model was created based on theory and the specification of requirements. The goal was to visualise production statistics and the concept model will illustrate one example in how this could be maintained. The concept model was illustrated with HTML since it was a suitable way to express the developed interface with the general appearance found in the current CQV interface. The concept model represents an interface that allows visualisation of production statistics to be presented.

4. Theory

This chapter presents how to design an interface with the human in mind and theory related to production statistics. This chapter aims to support the development of the concept model.

4.1. Design for the human

The design of a user interface should enable the user with easy access to the information needed in order to perform the tasks in a safe and secure way. It should guide and support the humans cognitive ergonomic and the users´ mental and physical disabilities need to be taken into account in the design of a user interface.

When designing a system, there are limitations not only from the computer system side but also from what the human system can handle. The human brain can handle a lot of different perceptions at the same time, but to be able to create a comfortable environment some conditions need to be concerned. When designing a new system with new features it can be hard to directly understand how to use it, therefor it is sufficient to use logics and symbols which supports the users cognitive ergonomics. Inventing a totally new system can be rather interesting for the designer but can cause distraction from the purpose of the system for the users. Good cognitive ergonomics will likely lead to less resistance and easy usage. The designer should have in mind that a display should help the users to perform their job as good as possible and not the opposite (Bohgard et al. 2010).

To create an interface with good cognitive ergonomics that draws the attention to the right place it is essential to use familiar symbols and sounds (Bohgard et al, 2010). People have their own mind maps in how to read symbols and a development together with the users will bring an idea of what symbols to use to create a self-explaining environment. Something to have in mind when choosing colours is in general that no more than four colours should be used (Bohgard et al. 2010).

The brain creates mental models from situations in daily life, which can be seen as a human brain algorithm. The human brain is able to process, mix and compare information from many different senses and decide how to handle information. As for the memory, it is known that the brain can keep 7 ± 2 items in the short term memory, it is important to design with this in mind to not force the users to remember things in order to perform their job (Mattsson, 2014).

Things to have in mind in the design phase to support attention, perception, memory and mental models according Mattsson (2014):

1. Design to minimize the time to find information
2. Keep the information close to where the attention is
3. Use multiple senses such as hearing and sight
4. Present information on correct angled displays with high contrast and good illumination
5. Design for good readability: font, colour and size of the text

6. Avoid knowledge based information, have in mind that the design should suit a wide scale of individuals
7. Use redundant information to support the user
8. Avoid having similar symbols and sounds to minimize confusion
9. Design to minimize the use of short-term memory
10. Try to give the users proactive information, forecast the situation
11. Consistent representation
12. Illustrate realism if possible
13. Dynamic information can be reached using movable objects

A system that supports the user can create a work environment where the user is active and alert (Berlin and Adams, 2014). Overwhelming the user with information will probably not draw attention to what is important. An agile design, designing in cooperation with the user, could serve the user with sufficient information in order to take good decisions (Bohgard et al, 2010). A system should have short term memory support and redundancy to highlight important information according to Bohgard et al (2009), as well as support the user with information in a non-complicated way.

4.2. Collect statistical data

When it comes to measuring there is a question of *why* it is in need of measurement and *what* to measure to maintain the requirements that contributes to quality of the process. Organisations today seem to have a high focus on measuring but it is common that this data never gets the attention or useless for its purpose (Hammersberg, 2012). Connecting an object to the process could enable essential data to be related to a certain time capture.

The use of statistics can contribute to detecting patterns and trends that otherwise most likely would go missing when analysing a big amount of data. A computer is constructed to perform quick calculations while a human is better to determine if right information is selected. Today there are algorithms that can detect patterns from large amounts of data (Vetenskapens värld, 2014). More opportunities are provided when more data is available to base decisions on as well as the analysis becomes harder. Subgrouping data is one way to handle a big amount of data (George et al, 2005).

4.3. Graphs

Graphs can be used to present data. The ability to take decisions from a self-explaining graph will likely contribute to faster decision making. Different data charts can tell different things. If things are presented correctly a better a more qualitative decision can be taken (Hammersberg, 2014).

There is various ways to collect data and also options to describe and to visualise data with the use of statistics. Graphs can be used in ways that gives easy access to information for the viewer and other can distract and complicate the situation. The selection of control charts can vary depending on what type of data, example continuous or discrete, that should be presented.

Time series plots

Time series plot can be used to visualise things that vary over time to also present in which order they occurred, *figure 4-1*. A time series plot diagram can be constructed without advanced statistical software. Another advantage is that it is easy to interpret without deeper statistic knowledge and gives the possibility to see trends and process variation (George et al, 2005).

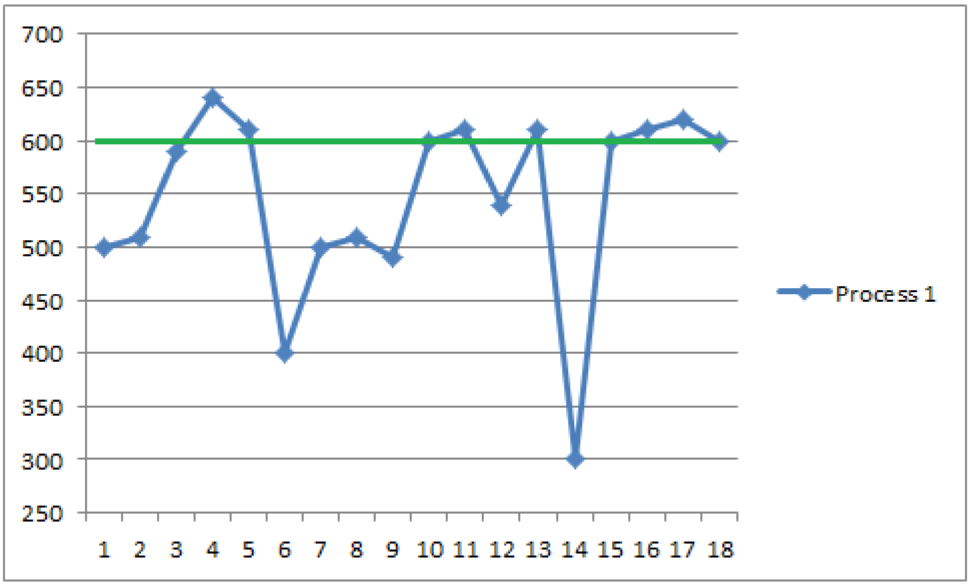

Figure 4-1 Time series plot.

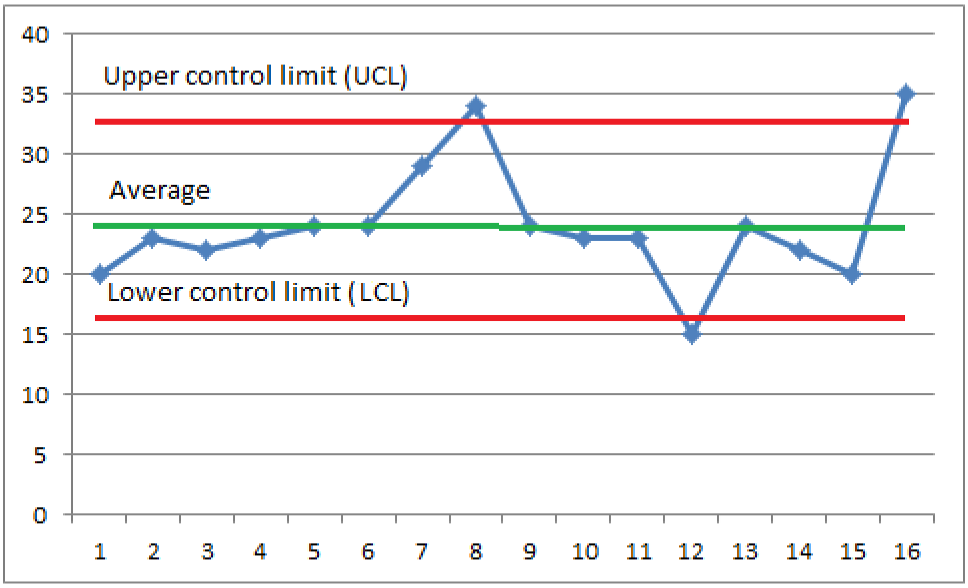

Figure 4-2 Schematic control chart with warning lines.

More diagrams can be found in the book *Statistical Process Control* written by Oakland (2008). Lines such as warning lines can be implemented in order indicate deviation in the system (Oakland, 2008). *Figure 4-2* presents a diagram with warning lines in form of upper control limit (UCL) and lower control limit (LCL).

4.4. Production statistics

This chapter presents commonly used production statistics and work tools included in Six Sigma and SPC. The sub-chapter aims to give the reader a brief explanation of production statistics.

4.4.1. Six Sigma

The name Six Sigma is taken from the math where the Greek letter σ (sigma) is used to denote the spread value of a standard deviation. To reach Six Sigma quality the process shall have less than 3.4 defects per million opportunities (DPMO) according to eHow (2014). Six Sigma is a method that can be used for different types of projects such as improvement projects.

Methodology - DMAIC
Five phases are explained in the Six Sigma methodology to in a structured way handle problem solving. The five phases are:

- Define
- Measure
- Analyse
- Improve
- Control

The method is referred as DMAIC. The methodology for improvement projects DMAIC in Six Sigma requires involvement from the employees at various departments in an organisation in order to keep the knowledge and continue the development. DMAIC is more detailed explained in *appendix C –Six Sigma*.

Measurement System Analysis
The purpose of measure system analysis (MSA) is to determine if the system can generate quality data, data with required accuracy. It is not uncommon that 30-50% of all measurement systems found in a company is incapable of delivering accurate or precise measurement. Gauge R&R, Bias analysis, stability analysis, discriminant analysis and kappa analysis are all types of MSA. Measurements need to be both accurate and precise. Accuracy and precision is not the same thing meaning that they have independent properties (George et al, 2005).

The goal is to have data with absolute accuracy (George et al, 2005). *Figure 4-3* illustrates combinations of accuracy and precision. No 1 in *figure 4-3* indicates that the process may be accurate but imprecise. In no 2, the process is both accurate and precise also referred as absolute accuracy. In no 3 inaccurate and imprecise, and last no 4 inaccurate but precise.

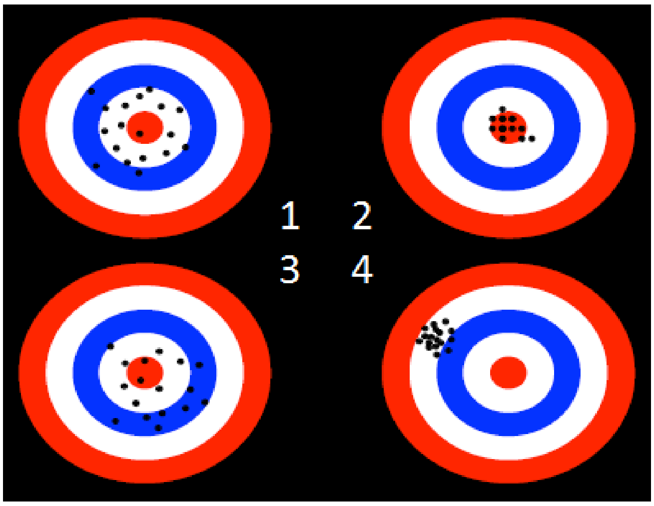

Figure 4-3 Accuracy and precision (Hammersberg, 2014).

Gauge R&R

Gauge R&R is a statistical tool that evaluates the repeatability and reliability of a measurement system, meaning that it is used to measure the measurements error in a process. The ideal is to receive the same result regardless of the person that performs the measurement.

Repeatability in a measurement system refers to the natural variability that occurs when measurement are performed under the same conditions. The same condition means when one person performs the measurement, with the same method and instrument and the same environmental conditions every time. Reproducibility is the variation that occurs when different persons perform the measurement with the same instrument, conditions and techniques (George et al, 2005).

4.4.2. Statistical Process Control

Statistical Process Control (SPC) is not only a toolkit but also a strategy for reducing variability, cause of most quality problems, product variation, in times of deliveries, possible ways of doing tasks, in material, attitudes, equipment, maintenance, everywhere in a systematic way.

Everything in an organisation that;

- requires understanding
- has variation
- must be properly controlled
- has a capability
- needs improvements

can according to Oakland (2008) be counted as a process.

Control

All too often processes are adjusted after just a single measurement has been performed. Even if the process is stable it still occurs random and common causes of variation making a one sample adjustment not sufficient. Oakland (2008) argues that it is essential to take 4 to 12 samples to provide sensitivity which can detect a change of the mean of the process. From this a suitable corrective action can be taken. If a sampling size is larger than 12 the range value will lose efficiency due to the values in between highest and lowest are not presented.

Data collected as variables is presented in a mean and range chart, presented in *figure 4-4* respectively *figure 4-5*. This makes it possible to see if the $\bar{X}$ (sampled mean value) lies in the range $\pm 3\sigma$. If the process is stable this should be the case. If $\bar{X}$ is in a rising or falling trend relative to the process mean the process needs to be adjusted, this yields also when $\bar{X}$ is below or above process mean. The process mean is the calculated mean value for the process.

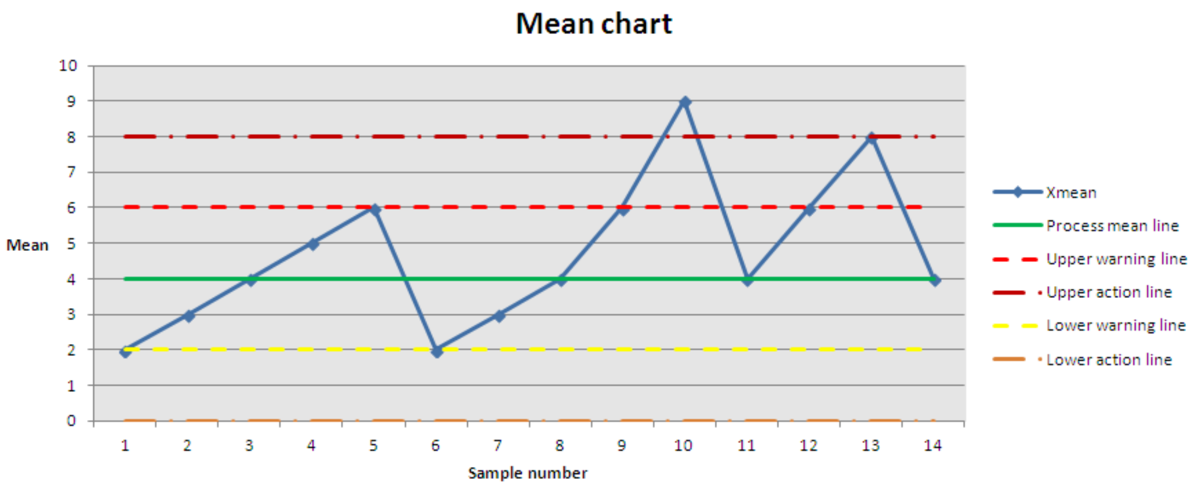

Figure 4-4 Mean chart.

In the mean chart there are upper action, upper warning, process mean, lower warning, and lower action line at:

- Process mean line : $\bar{\bar{X}} = Average\ of\ \bar{X}$
- Upper action line: $\bar{\bar{X}} + \frac{3\sigma}{\sqrt{n}}$
- Upper warning line: $\bar{\bar{X}} + \frac{2\sigma}{\sqrt{n}}$
- Lower warning line: $\bar{\bar{X}} - \frac{2\sigma}{\sqrt{n}}$
- Lower action line: $\bar{\bar{X}} - \frac{3\sigma}{\sqrt{n}}$

where $\sigma = \frac{\bar{R}}{d_n}$ and d_n is Hartley´s constant. $\bar{R}$ is the mean range of a sample and n is the sample size (Oakland, 2008).

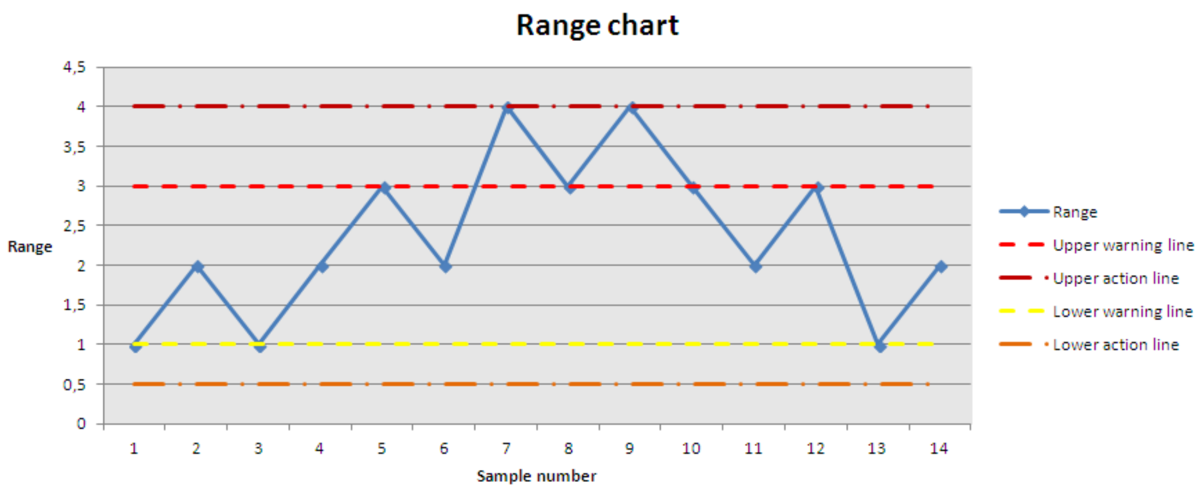

Figure 4-5 Range chart.

In the range chart action and warning lines are not symmetric due to range only can be 0 or higher and will instead be:

- Upper action line: $D_{0.001}\bar{R}$
- Upper warning line: $D_{0.025}\bar{R}$
- Lower warning line: $D_{0.975}\bar{R}$
- Lower action line: $D_{0.999}\bar{R}$

If the process is in control:

- No mean or range values outside the action limits
- No more than 1 in 40 values between warning and action limits
- No case where two mean or range values lies after each other outside the same warning line
- No runs or trends of five or more which is in the warning zone or action zone
- No runs where more than 6 sample means lies either above or below the process mean.
- No more than 6 samples of the mean being in a rising or falling trend.

Attribute

Collected data in forms of attributes, or in other term Booleans, makes it impossible to use mean and range charts to control the process. There are two types of control charts to control a process when having attribute data (Oakland, 2008):

- Number of defectives chart
- Number of defects chart

The Defectives chart with constant sample size is called np-chart, with samples of varying size it is called p-charts. Defects chart with same size of sample every time is called c-charts and with varying sample size called u-charts. Np-chart is used when there is possible to maintain a constant sample size.

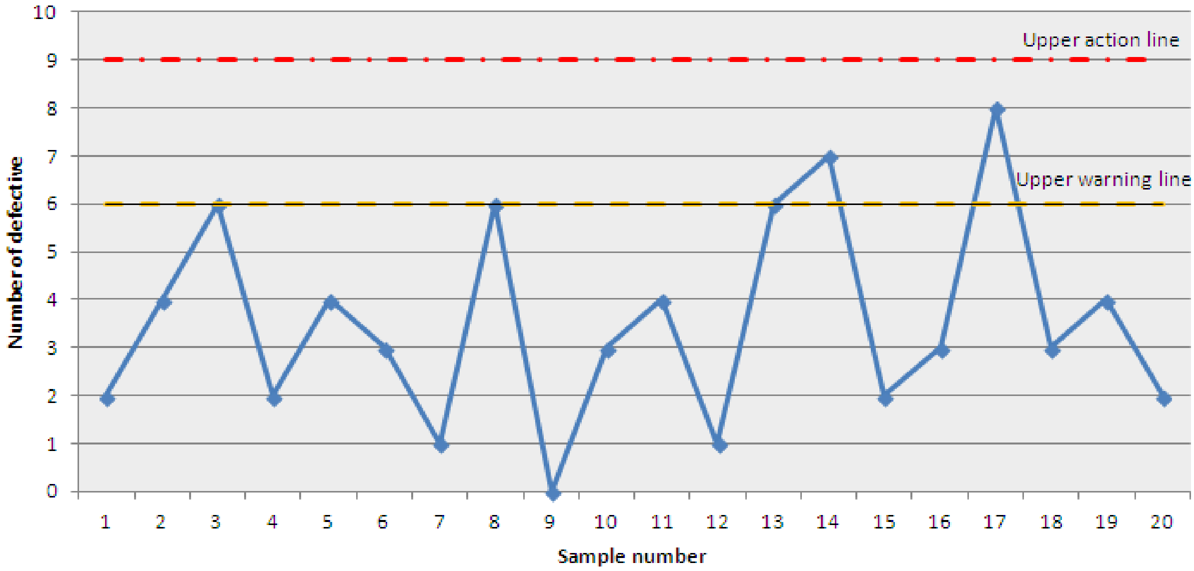

Figure 4-6 np-chart.

The goal with np-charts, *figure 4-6*, is to present the defectives in a constant sample size *n.* The centreline is $n\bar{p}$, warning lines $n\bar{p} \pm 2\sqrt{n\bar{p}\,(1-\bar{p})}$ and the action line is $n\bar{p} \pm 3\sqrt{n\bar{p}\,(1-\bar{p})}$ is the proportion defective, $\bar{p}$ is average value of *p* (Oakland, 2008).

When it is impossible to maintain constant sample size *n* a p-chart, *figure 4-7*, may be used. It is similar to np-chart but instead of having constant upper action and warning lines moving depending on the sample size.

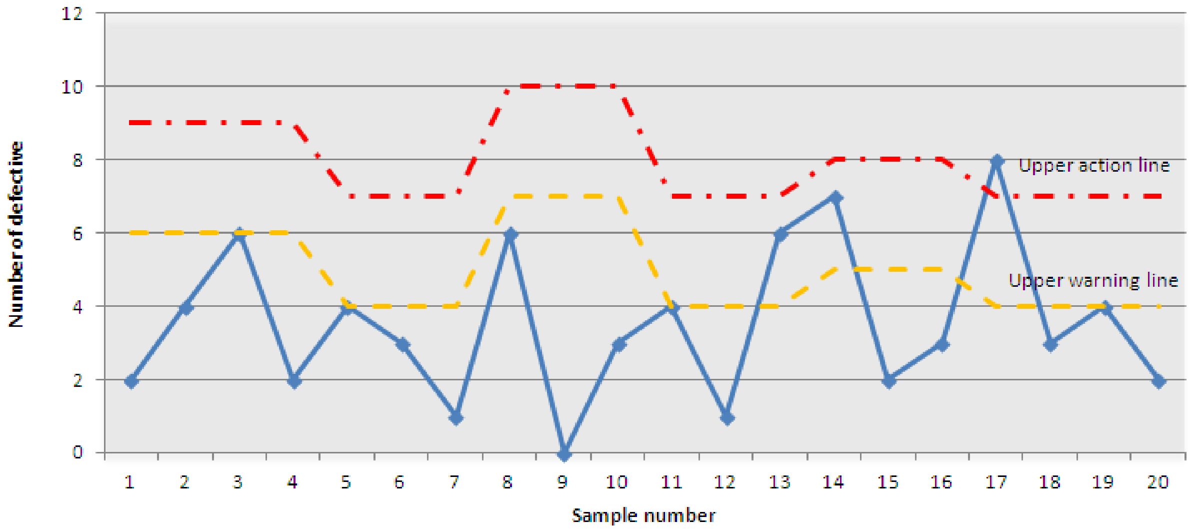

Figure 4-7 p-chart.

The p-chart has a centreline $\bar{p}$, warning lines $\bar{p} \pm 2\sqrt{\bar{p}\,(\frac{1-\bar{p}}{\bar{n}})}$ and an action line $\bar{p} \pm 3\sqrt{\bar{p}\,(\frac{1-\bar{p}}{\bar{n}})}$. $\bar{n}$ is the average sampling size. Note, holds only if *n* is in zone $(\bar{n} \pm 25\%)$ (Oakland, 2008).

5. Results

This chapter presents documentation from six interviews conducted at Company A, and two observations at Company B and C. This chapter will contain all material collected in the interviews and observations. At the end of each sub-chapter presents a conclusion named *main points.* Preferably those can be studied if the reader wants a quick summary of the content.

5.1. Stakeholders

The snowball recruitment regarding the participants for the interviews originates in recommendations from the determined participant from Company A, the process engineer. The interview participants represent the identified departments from the pre-study; manager of the production unit, the quality department, process engineers and operators. *Figure 5-1* presents a map with the participants in this data collection.

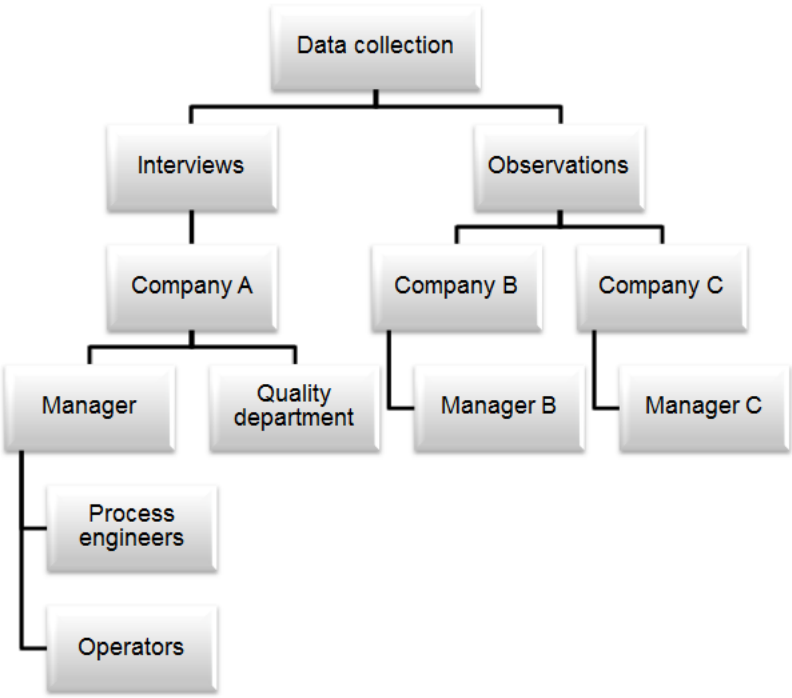

Figure 5-1 Data collection map that presents participants for the interviews and observations.

The first sub-chapter *5.2 Interviews* presents the data collection from Company A, and the two following contains information received from observations at Company B and C.

5.2. Interviews

During the personal meeting with the interviewees was an interview template used to support the interview. The interview template can be found in *appendix A - Interview template*. Below presents the main questions:

- *How long have you been working here?*
- *Your responsible areas?*
- *Manually performed tasks that preferably could be automatized?*
- *Other areas where machine vision can be used?*
- *Do you think that there are limitations in the CQV system today?*
- *What production statistics do you use/or can be found in your work?*
- *Which problems are repetitive?*
- *Are there any emergent problems?*
- *Do you find it important to have the possibility to predict problems?*
- *How do you want information to be presented on a screen?*

The interviewees were interviewed one by one, except for the novice operators where two operators were interviewed at the same time. Totally six interviews were conducted with following participants: one from the quality department (*sub-chapter 5.2.1*), one technical production manager (*sub-chapter 5.2.2*), two process engineers (*sub-chapter 5.2.3* and *5.2.4*) and three operators (two novices in *sub-chapter 5.2.5* and one expert in *sub-chapter 5.2.6*). The interview with the two novice operators will be presented in one sub-chapter. Following sub-chapter presents the conversation from the interviews, observe that the notes are written by the researchers.

5.2.1. Quality department

In an email correspondence with Q (2014a) was a list revived. The list presented errors prioritized based on the company´s biggest cause of complaint:

1. Adhesives on front panels, chunks of adhesive instead of thin lines which damaged the product
2. Final packaging, holes in the plastic bags
3. Elastic threads were sometimes missing, made the product unusable
4. Hard pieces found in the absorbing mass, no quality control performed on the mass section
5. Final packaging, time stamp on the product the plastic bags and the carton were missing

The following text represents the notes taken at the personal meeting with Q (2014b). Q has worked at Company A for the last 20 years, with a current position that involved quality control. The interviewee performed improvement projects on daily basis with MiniTab and

PlainQ. MiniTab is a statistical program that serves the user with information in order to take decisions to improve quality (MiniTab, 2014). PlainQ is statistical software developed by Company A to assess quality reports, and visualisation of graphs. The interviewee would like the CQV system to enable variable data, due to the fact that variable data give more information and can show trends easier than the attribute data.

As the lists of errors presents, product related problem mentioned could be areas where machine vision preferably could be monitoring according to the interviewee. Collecting production data is also a future area for machine vision. Parameters from the process connected to the product could contribute to the ability to see trends and take actions before errors occurred said Q. In many of the cases the quality department could figure out when an error is about to occur. The interviewee mentions that, by experience, the quality department could for example tell that some of the deviation found in quality of the product is due to that the machine was ramping up when the measuring took place.

The interviewee mentioned other areas where machine vision preferably could be used. In the current state there was no control of the final product, no control that confirmed that the final product remained correct before going into the local warehouse. The interviewee suggested that vision could be used to take a picture of the complete product. Further, an UV-camera distinguishing chunks of adhesives in the final product was also something that the interviewee found useful due to their list with customer complaints. Surveillance of creases in material, due to that creases in the material leads to incomplete joining when welded or glued. Also the final enclosure of the plastics bags could be monitored, since their only way to control this in the current state was to open the sealing.

The interviewee was questioned about how to visualise information and answered that the operators most likely was interested in information that contributed to the possibility to take fast decisions. Other divisions at Company A such as quality department wanted raw data to be sent to their existing statistical programs. But the operators might get support by an interface that gives an alarm if the process strives towards a control limit. Experienced operators are trained in localizing the error when the process stops.

The tests that the operators performed every 15 minutes as mentioned in *pre-study*, where four products were tested in order to ensure the quality in real time. Quality tests were regarding the panels and measurements of the final product. Once at every time shift, the operators were measuring the weight of the products to ensure that the absorbing mass in the core was correct. Quality department also performed tests regarding the products weight, where five products were measured to distinguish the mean and range in PlainQ. The company works with MSA on their processes and on the employees that performs the manual testing. Automated testing would most likely contribute to get a repetitive and accurate test procedure.

The interviewee expressed the benefit with saving pictures of the final product, for at least five months but preferably three years. These pictures could later on be used to support the department of complaints. The possibility with saving the pictures could contribute to backtrack and allow the company to look at old pictures. The pictures needed to be stamped with a time stamp, in the current state the local time in the plant were hard to sync with those stamped on the product. Q states that it was needed to make the sync better in order to make it enable to backtrack.

In the current state quality department received information about the quality of the product but received no data from the process. The interviewee mentioned one case where a clutch to an adhesive pump was not working correctly and this affected the quality of the product. By supplying the quality department with more data from the process, the quality issue can be easier to locate. This could also later on lead to improvements projects where they can increase quality as well as minimize the use of material or power, which also could mean saving money.

> *"Measuring means that it is possible to see where improvements can be made."*

The control of the amount of absorbing mass in the core is today measured in a test where the finished product is submerged into a bath in 30 minutes and then centrifuged. The amount of mass is then calculated via the weight of the product. If it is possible to see the amount of absorption mass in the core with machine vision, this could exclude the time consuming manually performed tests.

Main points
This section sums up the personal meeting with Q. Below are a conclusion presented:

- Enable quality assurance for the panels regarding the adhesive process
- Collect data from the process regarding the pressure and the number of revolutions in the adhesive pump
- The final product
    - Detect chunks of adhesives on the final product
    - Control of all parts are included in the final product
- The core
    - Measure length
    - The weight of the absorbing mass
- Creases of the material that occurred in the process
- Enclosure of the plastic bags
- Employees can perform manual tests different

5.2.2. Manager

The personal meeting with a manager of the production unit is presented in this sub-chapter. The manager (M, 2014) had an education within mechanical engineering and previous experience from working as an operator, line manager and process engineer at the company.

To control the production they use software and documents like MiniTab, PlainQ (mentioned in *chapter 5.2.1*) with SPC tools. M expressed that if could be beneficial if CQV could report to PlainQ, this information together with other production parameters could make it possible to relate errors to a certain parameter in the future. One drawback with PlainQ is that it cannot handle real-time updates. M thought that machine vision could be used to detect trends. Collecting process parameters and connect them to the product would allow improvements such as traceability and standardisation.

Currently the operators received warnings from the process in the operator panel. To find trends would mean that pattern recognition needs to be handled by the system according to M. Repetitive problems that occurred were related to the adhesives, the core and the absorbing mass. M thought that it would be important to also control the final product.

When the interviewee was asked about what to visualise on a screen, the answer was that showing the most critical parameters would most likely enable the operators to perform on a higher level. Parameters could be from both the process and product, actual value and set value could be displayed with a green or red background to express the state of the parameter. To find which parameters to present and how they war related to other problems in the process were something that Company A need to further investigate.

M would like to find a reliable setting list that tells how to deal with each situation and from that improve and eliminate the root cause. A sort of PDCA, called DDS, method was used with the intendancy to standardise and improve the process related tasks.

At the current state Company A only used machine vision to register product parameters. To also monitor process parameters was something that the interviewee found interesting. At the moment the registered parameters from the process were mainly performed manually which made it impossible to connect it to the product later on.

Main points
Sum up from the interview with a manager at Company A:

- The need for graphs may not be important for the operator
- Use green and red colours in the main display to get the operators attention and have more information available if the user wants to find out more
- Elimination of manual control of the core and absorbing mass
- Control of the final product would also be preferred to ensure quality
- Critical parameters could be displayed on a screen for operators, both the actual value and the set value.

5.2.3. Process Engineer 1

The collected data from the personal meeting with the first interviewed process engineer (P1, 2014). P1 started to work at Company A as an operator and had been working as a process engineer for almost seven years. The process engineer was responsible to solve problems, perform improvement projects and to perform test runs on the machines.

When P1 was questioned about problems the answer was that critical and recurrent problems were regarding the panels and adhesive on the product and in the machine. The interviewee expressed low credibility for the CQV, for the reason that it just presented “ok” or “not ok” but gave no information about what the decision was based on. The interviewee explained that if the CQV validated correctly they need to manually control 60 000 products. This procedure would be needed to be performed for every new setup, approximately every eight hour. Analysing 60 000 products manually should take more than four years to perform. P1 explains that this validation process needed to be performed in another way.

“CQV is complex, therefore it is hard to understand how to use it correctly.”

Another issue with the classification at the current state was that if incorrect images were classed as a correct image, placed with the “ok” reference images, the result would incorrect. If the CQV interface could present a variable of a measurement, the classification score, an angle or a location, it would raise the credibility said P1. Using variables could also mean that the performed manual measurements could be excluded according the P1.

Using MVS to monitor process parameters could enhance the knowledge about their process. Together with the information from the PLC and other devices in the process unit the company would be able to analyse the process according to P1.

P1 explained that there was a benefit of having the saved images stored for at least a year. This should not only be a support for the customer complaints department but it will also make it possible to analyse decisions taken by CQV. It gives also the possibility to go back in history when a new error is found.

The interviewee found it important to find the root cause of a problem, which commonly led to long lead times due to that data needed to be collected before the analyse begun. A system that supports the process engineers with parameters would be useful in order to make their work more effective.

Main points
Conclusion from the personal meeting with a process engineer, where the following topics were discussed:

- Control of the final product could be in use to control the complete product. The image could be saved in order to enable a picture of the product in customer complaint situations.
- Common that the classification of the CQV does not work properly, high amount of scrap with no information of why
- Validation of the current CQV platform
- Variable data is more useful than attribute data
- Present score assessment of the classification of an image
- CQV is complex, has low credibility and at the current state there was no way to see how decisions were made

5.2.4. Process Engineer 2

In an email correspondence with process engineer (P2, 2014a), P2 expressed that it would be beneficial for Company A to have a system that has the ability to indicate recurring errors. At the current state they already knew applications where this could be useful. In the quotation below presents a part of the received email where P2 presents two new application areas for machine vision related to the cutting process for the four panels:

“Let's say we have a failure in a vacuum hose in one of the two applications on an applicator with 9 applications per lap. This allows the application of the material not be correct at one of nine. On another occasion it may be wrong every sixth time, then the reason that an error occurs can be an applicator with six knives where one of the blades is worn out. There is important information for the operators, because they know where they should begin to troubleshoot.”

The process engineer explains that the benefit of saving pictures was that it could visualise things that was unforeseen in the implementation phase. The following sections present the material from the personal meeting with P2 (2014b). P2 supervised the pre-study tour and was the most experienced in field of machine vision at Company A.

P2 explained that the current machine vision platform could preferably be developed to cover more areas. An example of this was the control of the four panels, as mentioned earlier in the email correspondence. One commonly seen problem was that adhesives end up at the cutting knives in the machine which resulted in not properly cut panels. Other areas for machine vision were to detect where the adhesive were mounted or to control the final product.

The process engineer mentioned how blob algorithms could be used as a compliment or replacement to *Manto.* The benefits of using blob algorithm is that this algorithm takes faster decisions compared to *Manto* and can be operating directly by implementing limits from the product specification according to P2. Another benefit of using *Blob* was the time to base the decisions, blob takes one millisecond while *Manto* takes 20 milliseconds according to P2. Blob also gives an actual value. Adding a graph in the CQV interface that presents the validation done by *Manto* would benefit Company A according to P2.

The interviewee said that it would be of high interest to have a system that can identify patterns which could open up the possibility to forecast errors and deviations. If the CQV would have possibility to present statistical data from the production it would be useful to present it in an additional tab in the CQV interface said P2. In this tab, graphs could be shown and the graph causing the alarm could preferably be prioritized and attention drawing.

Due to the saturated amount of software found in the company today the interviewee found no need for a new one, rather a something that connected the existing software.

The interviewee returned to talk about the benefit with the *blob* algorithm. Another benefit would be to help the operators to restore the process when an error occurred if the interface supported them with information from the process. The process engineer ended up the interview by saying:

> *“I believe that if we measure positions on well-chosen places with good control limits it is possible to detect problems and act before an error occur*”.

Main points

Sum up from the personal meeting with a process engineer at Company A:

- Useful to have *blob algorithm* as complement or to replace *Manto*
- Show the score of classification made by the algorithm
- The ability to see trends and patterns
- Statistical data of errors, the ability to connect process and product parameters
- Graphs could be presented in an additional tab in the CQV interface
- No more systems needed at Company A
- *Manto* cannot predict

5.2.5. Novice Operators

This sub-chapter presents the content of the personal meeting with two novice operators (ON, 2014). These two operators were interviewed at the same time and their individual expressions are not distinguished. ON had a few weeks of experience from working as operators in the production unit. The reason for having two interviewees at the same time were due to the possibility receives opinions from two available employees.

Production personnel had a rotational schedule and changes responsible areas several times per shift, responsible areas were material supply, quality (measure and tests) and the process. ON mentioned the importance of the quality of the produced products and that stops often occurred due to the raw material change.

“Experienced workers may find the cause of the problem that caused the stop quite quickly”

ON said that it was comfortable to have experienced workers around to learn and perform at a high level, such as supervisors and team leaders.

The manual testing commonly discovered problems that required the process to be adjusted or in worst case to be shut down to find and eliminate the root cause. If the manual testing could be excluded and done directly in the process, time spent on tracking faulty products would be minimized and resulting in decreased amount of waste according to ON. Commonly errors that made the machine to go down were adhesive on cutting knifes which resulted in faulty cut edges on the panels.

When a new model was about to be produced, approximately every eight hour, the system needed to be readjusted. Ramping up or down responded to that the quality of the products were poor and good quality was only considered when the process was stable. That meant that a lot of products were wasted every time the process was unstable. Repetitive problems due to the changeover often related to the final packaging, the cartons as well as change of raw material. The carton could cause trouble with the vacuum that held the carton in the final packaging process. Another problem found in production was the time stamp on the plastics bags. The printer occasionally stopped and there were no control securing that the date could be found on all plastic bags.

When ON got the question regarding what to present in an interface the answer was that it is only important to get information when there is deviation in the system.

Main points

The list presents the main points from the personal meeting with two novice operators:

- Cutting process for the edges of the panels fails due to adhesive attached on the cutting knife in the process.
- If they could receive a warning only if the process are reaching a limit, it could enable the operators to act only when needed and prevent an error to occurs.
- Highlight graphs and real-time measurements when there is a deviation in the system

5.2.6. Experienced Operator

This sub-chapter presents the material from the personal meeting with an experienced operator (OE, 2014). OE had worked as operator for three years with main responsible areas to keep the machine up and running and to fix minor issues.

OE explained that the operators used both the CQV interface and the operator panel. When the scrap rate went up the operators watched the images generated and visualised in the CQV interface and on their operator panel to locate the problem. The errors were often complex and the decision were most commonly based on experience.

The most common error was regarding the panels of the product, the contour cut. Adhesives often caused the cut to be incorrect, this was an area that OE found interesting to monitor.

A limitation with the current machine vision was that it only could detect if everything was placed where it was supposed to be, not detect if something was missing. Neither the possibility to detect if the mounted pieces were firmly attached. Due to the mentioned things, manual testing needed to be continued at the current state according to OE.

OE would prefer to see graphs, since it would most likely make the job easier and make it possible to locate the source of the errors. Errors and warnings from the machine vision should be sent to the existing operator panel. The alarms detected by CQV could preferably be both warnings and action demands.

Today they perform manual readings of pressure and vacuum in the machine. This related to the process parameter which is something that preferably could be noticed automatically by the process.

According to OE 99.9% of all products that were manually tested pass the control but the interviewee did not know how many “ok” products that *Manto* classified as “not ok” products.

If it is possible to find the parameters that caused the warnings it would be possible to find patterns and predict errors before they occur according to OE. But if parameters should be presented on a screen they should only be presented or to call for attention when deviation was detected, said the interviewee.

Main points

Sum up from the interview with the experienced operator at Company A:

- CQV was used as a tool to detect errors and its root cause
- Contour cut of the panels was the most common cause of an error
- CQV only examined if parts was located where they were supposed to be
- Show graphs to support the operators
- Alarms from CQV should be sent to the existing operator panel
- Monitor new areas to minimize the manual work
- Some parameters important to monitor were the adhesive pump's pressure and vacuum
- Only call for attention when deviation was detected

5.3. Observations

This chapter presents documentation from the data collection at Company B and C. The conducted observations were supervised by managers and included a guided tour in the production unit.

5.3.1. Company B

Company B is a global marketing leading company specialized in clinical nutrition, infusion therapy and medical technology. The healthcare industry is strictly controlled and inspections from external agencies representing a specific market, like FDA (2014) for U.S., are common. Healthcare industries require full control and delivered products must be verified repetitive times and with specified quality.

At Company B CQV was used for quality control.

Implementing new features that minimizes the amount of manual work was something that was hard in the healthcare industry according to the manager (MB, 2014). The requirements of redundant verification in order to ensure standardizations, rules and quality from external regulations are a big factor to this struggle.

One of the employees had ideas about a future system, or let's say an interface, one that could support the operators and explain what to adjust in order to maintain good productivity. In the future, the algorithms would preferably be self-developing. The employee also mentioned what is interesting with vision is that it enables data to be stored and analysed in another way compared to conventional systems.

The manager (MB, 2014) at Company B was responsible for special machines and handled issues regarding the production both in-house and external. The manager had over ten years of work experience of special machines and production related work tasks.

The manager found it useful to have an interface with different applications similar to an application store for mobile phones, *figure* 5-2. The benefit with this kind of application would be that the companies and departments can choose what applications that should be installed at their work station.

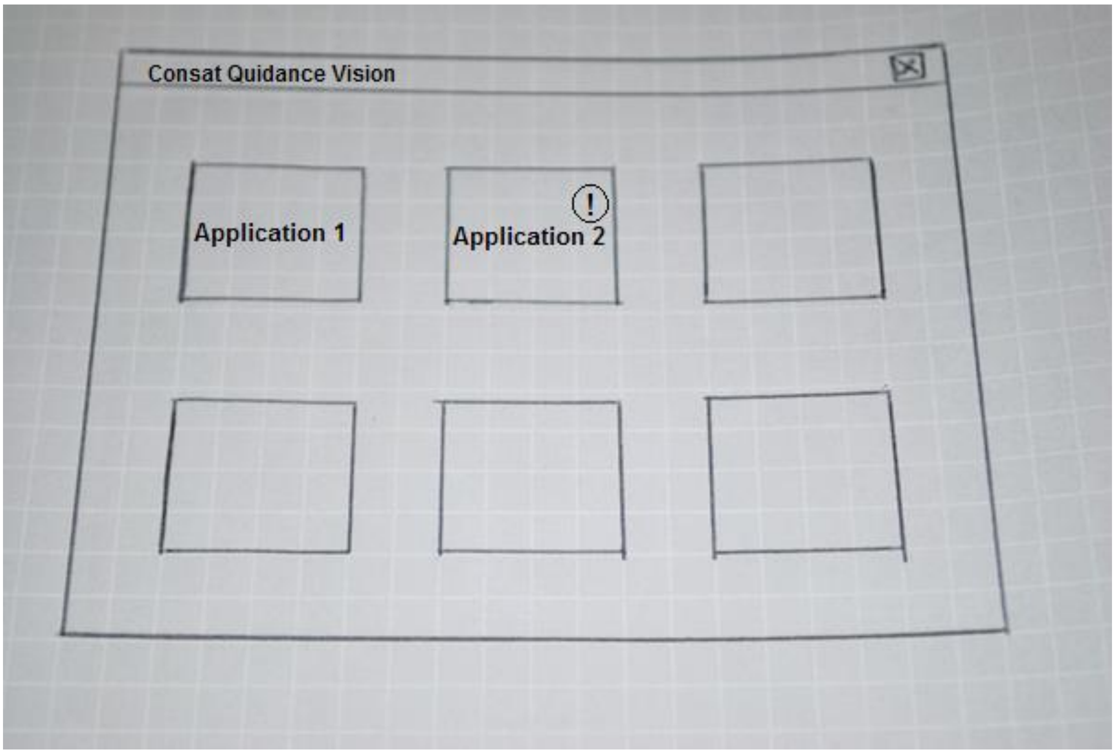

Figure 5-2 Illustration of an application store. An exclamation mark informs the user that an update is available for Application 2.

The manager explains that Company B could be in use of a system that collects information that allows information to be analysed externally. An interface that receives information from different devices, parameters from let's say CQV and a PLC, and present all information on one screen. If the system could send information to a server it would enable easy access to information externally. And the interface could, like an application store for mobile phones, tell when a new update is available, see *figure 5-2*.

One important thing that was mentioned by MB was that the system still needed to be able to run offline in case of lost internet connection. Making it possible to sync between factories will also be an advantage for a potential monitoring system. This would make it possible to have other factories to help and perform maintenance when problems occur.

"Where it happens, it must be seen"

If there is an error somewhere in the production some kind of signal must be given at that area, example a flashing bright light. It could also be a map over the machines where a red arrow points at the place where the error occurs giving the operator a fast view of where to start to solve the problem. It might also be good with an alarm with a text explaining the problem and its location. All for the reason to keep the user's alert to directly understand where things occur and how to solve it.

An ideal future system will be self-learning and able to by itself collect the right information to be able to see trends.

A mobile display would make it easier to bring the control panel and the surveillance information wherever the operator goes making the operator able to react faster when an alarm occurs.

The manager mentioned that it could be useful to monitor more than just quality inspection with a vision system. It could be used to monitor how often an operator needs to correct something in the production with a camera. Machine vision could also be used to view the stock status of less frequently used products as a way for the supply chain to plan delivery and purchases.

Today a line manager at Company B needs to visit the shop floor to note information regarding the production statistics. An interface that sends reports from the production on demanded schedule would eliminate the non-value adding tasks that are used today to get this information.

The manager had some examples of how an interface could look like and pinpointed the need for an interface that most users can be familiar with. *Figure 5-3* presents an interface based on MB´s opinions (2014).

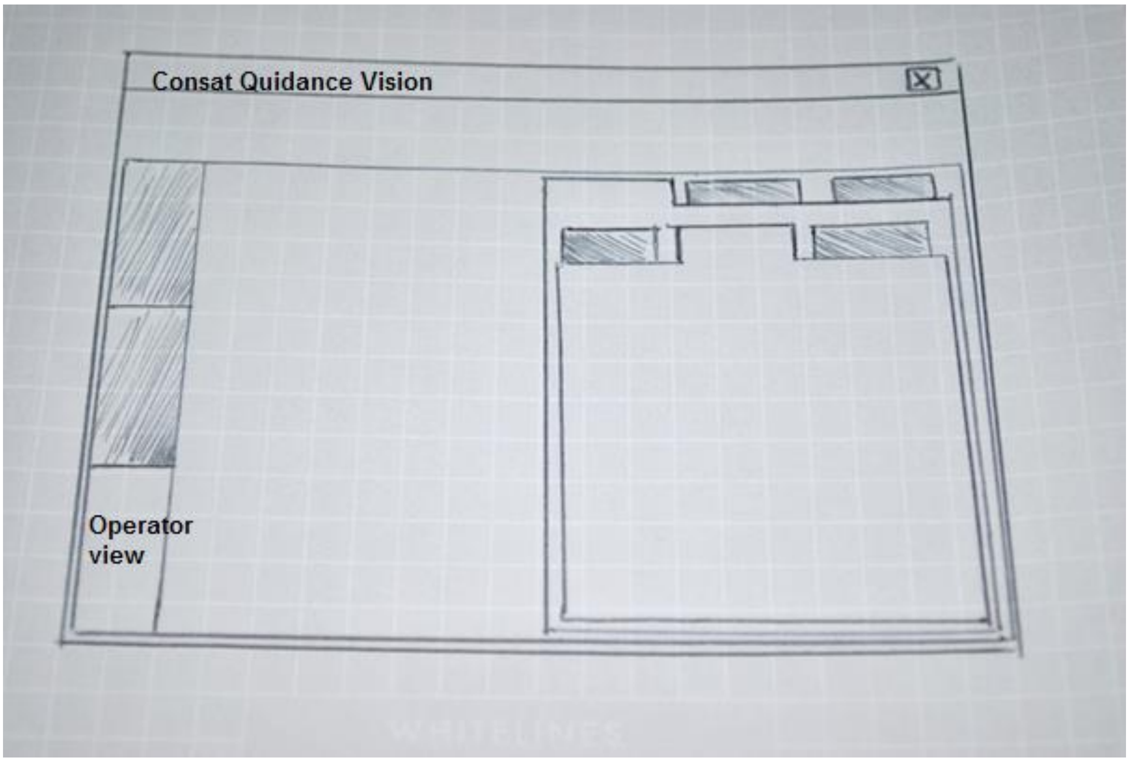

Figure 5-3 Illustration how tabs can be used to navigate in the interface.

According to the manager the operator, process engineer, line manager and controller could be stakeholders regarding the development an interface. The manager would like the developed CQV platform to be delivered with a standard package and have the possibility to send images to a server.

Other areas that MB found interesting were statistics and measurement that enables the system to see trends. For example, register how many times an operator controls and adjusts a certain process or task as mentioned before.

Main points
Sum up from observations at Company B:

- Offline availability
- Save images on an external database that allows external access
- Compatible with other software
- CQV as a subscription which informs the user about new updates

5.3.2. Company C

Company C is one of the world's leading companies in the bearing industry. The interviewee (MC, 2014) was a project manager in the process development department in a factory at Company C. The factory produced rings for bearings and the products were tagged with an id number. Company C tried to collect data and connect it to the product´s id to enable traceability. The level of automation in the factory was considered as very high, not many tasks besides material supply were handled manually. The manager mentioned that they have started to work with lights in order to call for the workers attention. A process with a light that belongs to a vision camera flashing could indicate where the problem has been detected. Turning off the lights in a process could indicate that it has run out of material or stopped working.

Machine vision was mainly used for inspection of the rollers surface, as scanners or for robot position. The manager´s view about machine vision is the possibility to see what is happening and also that it could monitor mew areas.

The company used statistical methods and software such as Six Sigma, MiniTab and their own developed software used for specific processes. Collected data should be able to support analyse of MSA and capability studies and easily be analysed in almost any tool. The manager also mentioned a new data collection project was established, that should via a cloud based database collect data, similar to what Volvo (Volvo, 2013) and SAP Hana (SAP, 2014) mentions as “Big Data”. This new project should enable not only future data analysis for Company C also the possibility to see trends. In a future scenario the big data project may contribute to the ability to predict future problems and from that control the process in the ideal way that ensures quality said the interviewee.

“Precision is the hardest thing to handle.”

The interviewee received a question about if it is something lacking when talking about control and measure, and answered that it is hard to ensure quality of a surface. Also the variation of sizes of the products is a variable that needs to be included which makes it even more difficult to create a suitable and predictive quality system. Another quality assurance was the control of machine setup changeover, where a vision system monitor if the process was done correctly.

The operators were mainly only interested in the status of the process and as the manager mentions, “they are the expert of the process”. If an error occurs they have experience that enables them to operate in the best way. A graph with control limits would enable easy access to the status of the process for the operators. In an ideal world the system could also tell exactly what was wrong and how to solve it or automatically solve it before the error occurred.

Possible stakeholders at Company C according to MC could be a process engineer and a technician or a person in a similar position as the manager. They would most likely be interested in raw data. Raw data makes it able to analyse in many ways. It is therefore important to collect data in a way that makes it possible to analyse it and preferably also compatible with Kudos or Microsoft Excel.

Main points
Sum up from the visit at company C.

- Operators needs easy control to ensure that their process is performing correctly
- Graphs with action lines
- Highlight problems with light
- No more software
- The ability to backtrack
- Use vision to ensure surface quality
- Use vision to ensure the tasks have been performed correctly

6. Analysis

This chapter presents the analysis of the data collection presented in the previous chapter. The statements found from the interviews and observations were translated and divided into categories with a KJ analysis. A function list was developed from the KJ analysis and mapped with a function three. The final result of the analysis was a specification of requirements, a foundation for the development of a concept model.

6.1. KJ analysis

The KJ analysis was performed with the statements from the data collection. The statements were grouped into themes and some themes got master headers. The themes, headlines and statements (written on yellow post-its) are presented in *figure 6-1.* The documentation can be found in *appendix B – Sorted statements from the KJ analysis*.

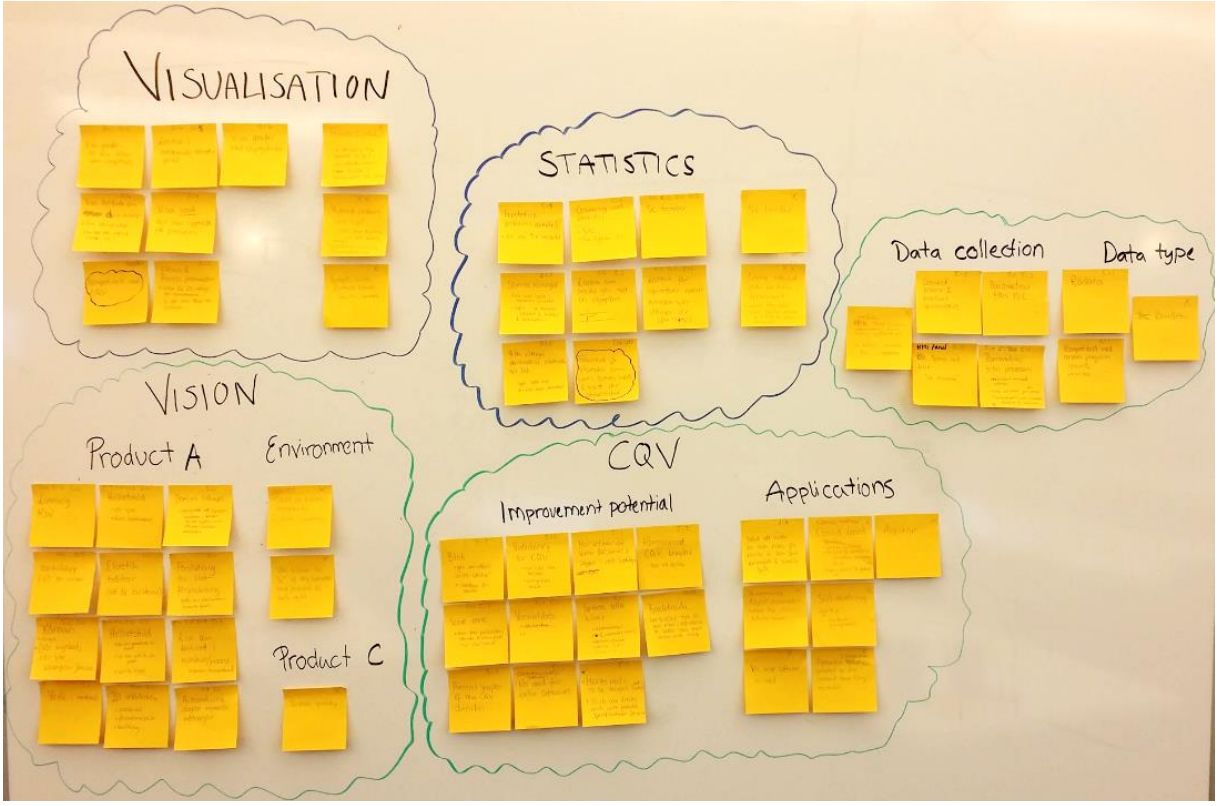

Figure 6-1 Picture taken at the KJ analysis.

6.2. Function list

The function list was developed from the results of the KJ analysis. The themes named *Statistics* and *Visualisation* were used for further analysis due to the purpose of this project and the other themes worked as support. *Table 1* presents the function list. Each function is presented with a verbs and a noun, every function has a classification and a clarification which demonstrates the importance respectively the function.

Table 1 Function list (M=Main function, N=necessary function, W=Wanted function)

	Verbs	**Nouns**	**Classification**	**Clarification**
CQV	Take	Picture	M	Take picture of the product
	Classify	Image	M	Classify the image and send error signal to machine if "not ok"
	Extract	Data	N	Withdraw data from image
	Find	Trends	W	Detect trends
Presentation	Show	Image	M	Show image taken by camera showing the classification and allow error view, present score of the classification
	Show	Graphs	N	Show graphs, production statistics, in the CQV interface
	Show	Param eters	W	Present the most critical production parameters, set-/actual value
Reporting	Send	Alarm	M	Send all alarms to operator panel
	Send	Data	N	Transmit raw data to external user/server
	Send	Report	W	Send a customized report with a specific interval

6.3. Function tree and specification of requirements

A function tree was established in order to understand the interaction between the defined functions in the function list. This function tree, *figure 6-2*, illustrates what should be included in the concept model. The function tree illustrates why the functions exist and how they are fulfilled. It also expresses how the functions support the stakeholders', presented in *chapter 5.1*, needs and wants.

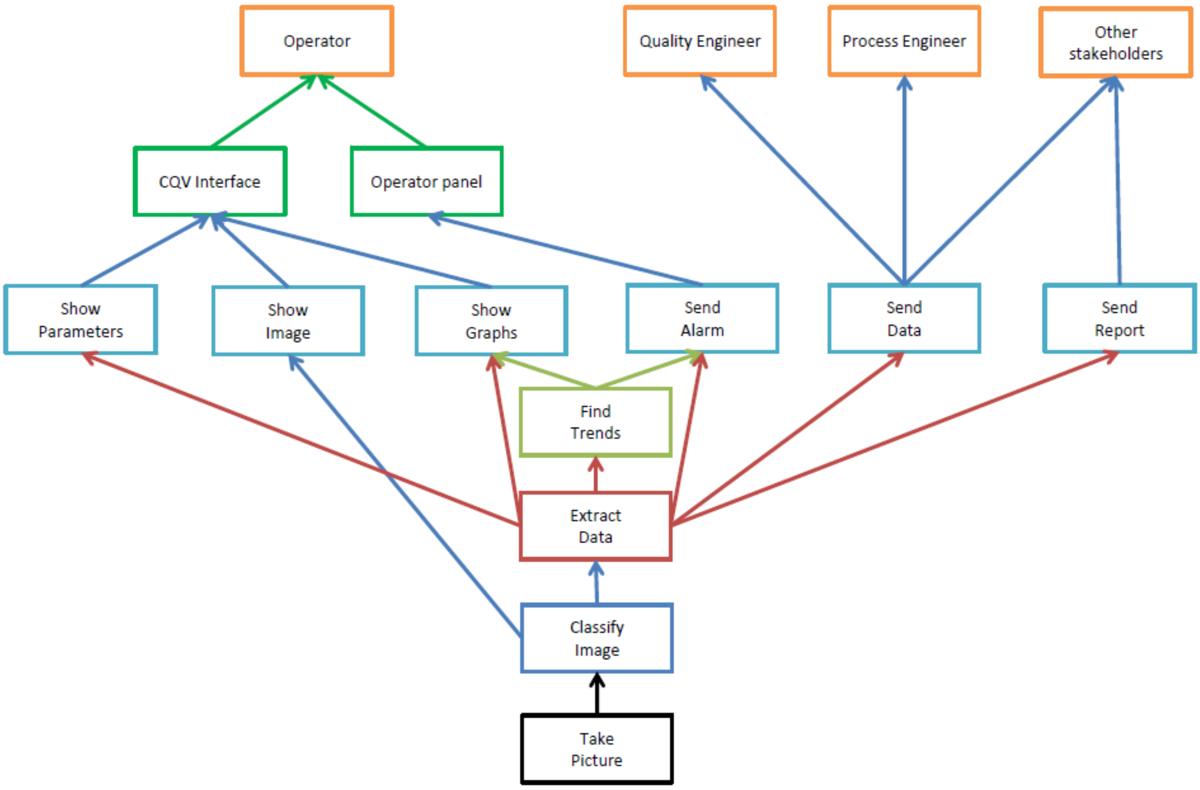

Figure 6-2 The function three presenting the relationship of the functions and the stakeholders.

The result of the analysis

Other stakeholders, on the top to the right in *figure 6-2* represents as mentioned in the data collection, other departments at Company A that could benefit from a developed CQV platform. As a result of the data collection and analyse it is shown that the development of the CQV interface at Company A will mainly affect the operators. The operators were at the current state the employees that use the CQV interface, as a complement to the existing operator panel. Due to this result, the operators are the beneficiaries for the development of the concept model that represents the CQV interface. But the development of the concept model also aims to satisfy other beneficiaries, like managers, employees of the quality department and the process engineers.

The specification of requirements aimed to satisfy the operators and the expressions related to visualisation and production statistics from the previous analysis. The result is shown in *table 2*. Each requirement got a clarification and a classification, demonstrating the purpose and the importance of the requirement. The requirements found in the analysis were used as a foundation in the development of the concept model, presented in *chapter* 7.

Table 2 Specification of requirements (M=Must, N=necessary and W=want).

	Requirement	**Clarification**	**Classification**
CQV	Classification of image	Present classification done by CQV algorithms	M
Visual	Graphs	Show graphs with limits	N
		Enabled in separate tab in current CQV	W
	Trends	Express repetitive problems	N
	Alarm	Show alarm only when deviation	W
		Show alarm in operator panel	M
		Send alarm if process strives towards a limit	W
		Send alarm when trend breaks is found	W
	Parameters	Show most critical parameters	W
	Design	Use the general appearance of the current CQV interface	M

7. Synthesis

The synthesis was based on the specification of requirement presented in *chapter 6.3*. Due to the fact that it was the operators at Company A that were using the CQV, the concept model will represent the development of the CQV interface focusing on expressions for the benefit of the operators at Company A. Due to the fact that there was no need to develop a new system at Company A as well as keeping the current general appearance of the CQV interface, the concept model will emerge from the CQV interface found at Company A.

7.1. Description of the current CQV interface

Figure 7-1 presents the current CQV interface at Company A*.* The view presents information from six cameras, at the time capture in *figure 7-1*, four cameras are available and two windows unused. This view is the start page of the current interface.

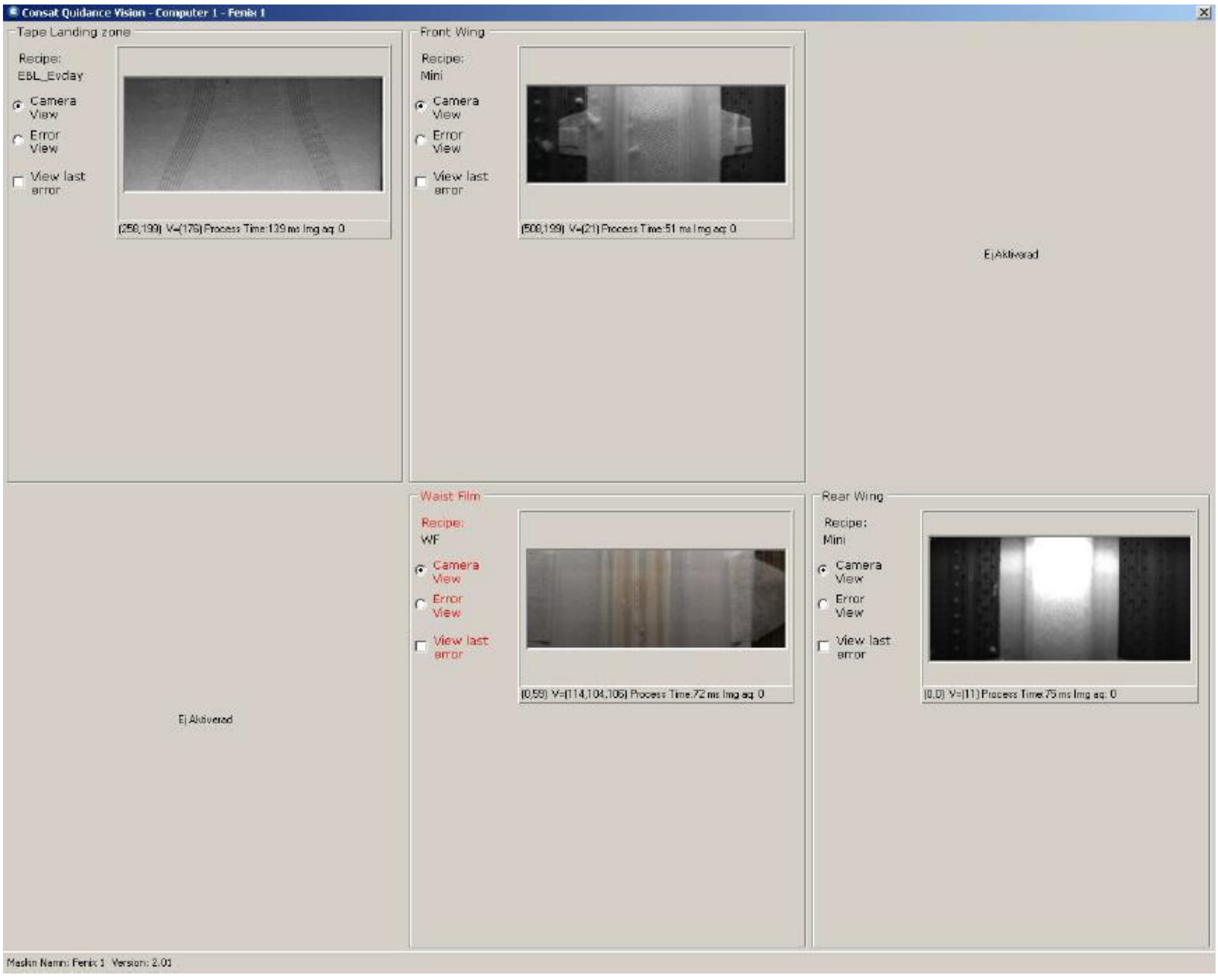

Figure 7-1 The standard view in the current CQV (Consat, 2014a).

The operator can choose between two views for each camera, *Camera View* or *Error View*. The *Camera View* displays the image, note that *Camera View* is activated in the four cameras in *figure 7-1*, until next one is received from the camera. Due to the high speed production each camera view will display approximate 13 images of the product every second, making it look like a movie.

The view can also be extended with *View last error*, *figure 7-2.* This extension is showing the last error until a new one is captured.

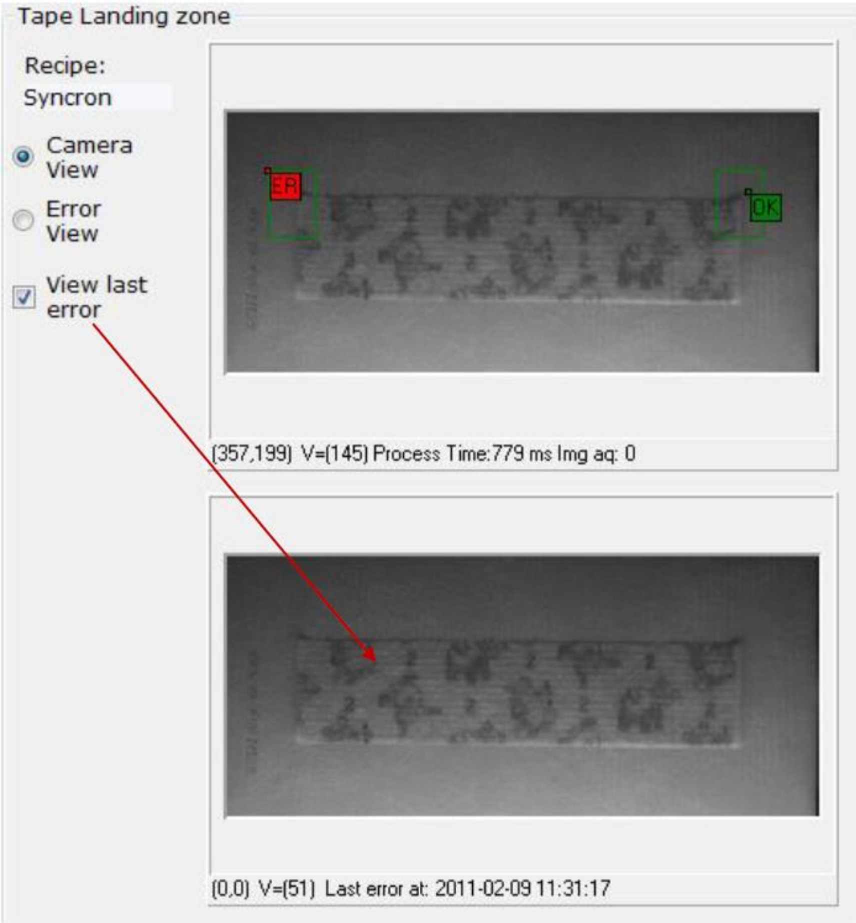

Figure 7-2 Last error view for one camera in current CQV interface (Consat, 2014a).

The second view is *Error View*, shown in *figure 7-3*. The errors are stored in a chronologic list were times tamp and error cause is displayed. It is possible to browse in the list and look at previous errors.

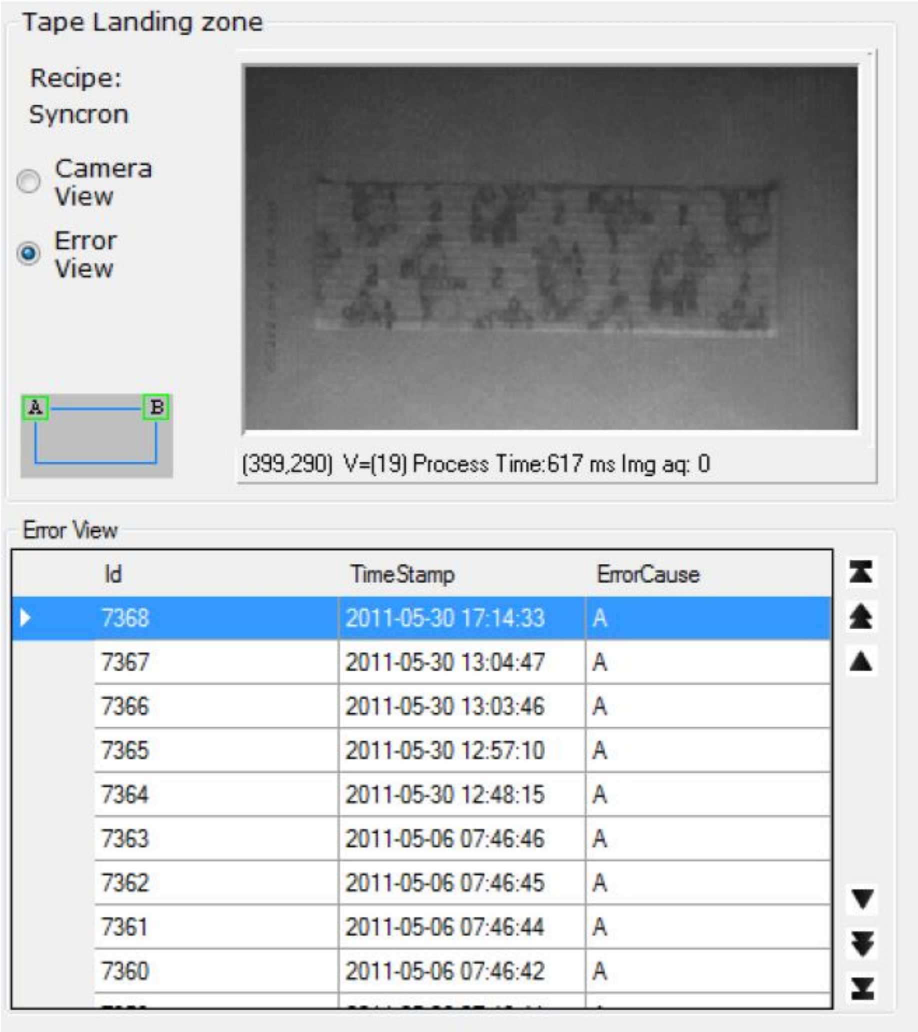

Figure 7-3 Error view with chronological list (Consat, 2014a).

The benefit with the current CQV interface is that it is easy to use, as there is only one main window that presents information. If the CQV detects a major issue the operator can inspect the images and locate the issue. The downside of the current CQV interface, according to the stakeholders' opinions, is that it does not supply the user with information regarding any statistics, measurements or score of the classification.

7.2. Concept model

The concept model represents a developed interface based on the stakeholders' opinions. The concept model was based on the analysis in the previous chapter and theory. In the concept model six cameras was chosen to be illustrated.

The development of the concept model aims to satisfy the stakeholder needs related to visualisation of production statistics. The model was designed with the general appearance found in the current CQV interface. Alterative tabs and windows were added to allow new features to be implemented. The original start page was kept as an alternative view but not as the start page. The following figures presented in this sub-chapter illustrate how the interface would look like and the content that should be presented in the empty windows will require further investigation projects at the company.

The design of the concept model is generally a menu to the left and a window to the right, *figure 7-4*. In this model will four alternative views be available, named *Main View*, *Camera View, Graph View* and *Analysis View*.

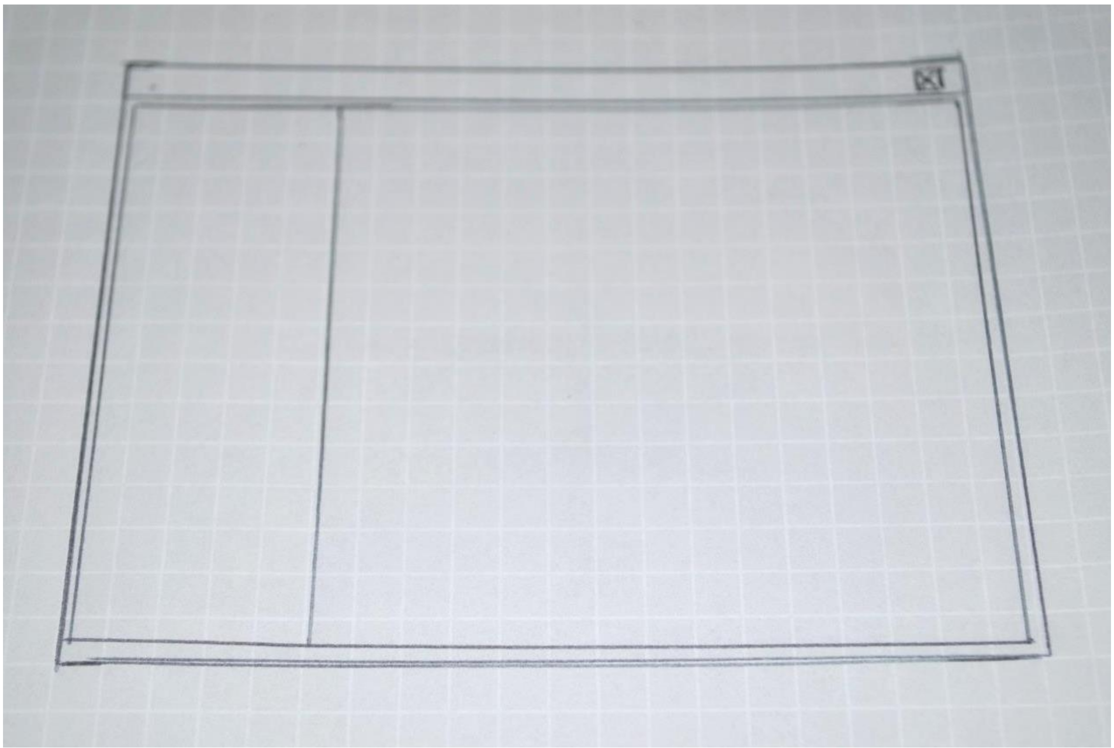

Figure 7-4 Interface layout.

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Following statements were included in the development of the concept model:

- *Present score of classification done by CQV algorithms*
- *Show graphs with limits*
- *Express repetitive problems*
- *Use the general appearance of the current CQV interface*

The statements were the core in the development of the four views. In the concept model will the *Main View* be the start page. All four views will present different information based on the specification of requirements from *chapter 6*. The views are explained later in in this chapter. The hierarchy of the concept model and how to navigate is presented in *figure 7-5*.

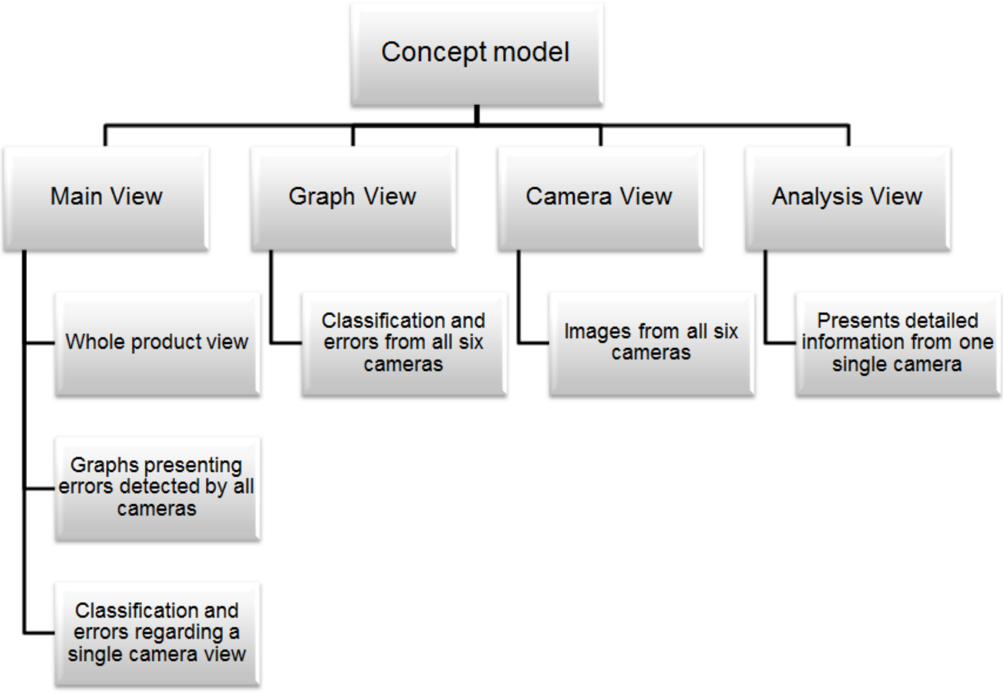

Figure 7-5 Presents what information that can be found in each of the four views.

Figure 7-6 presents the new start page called *Main View.* This view will present information of the whole product, graphs with detected errors and classification.

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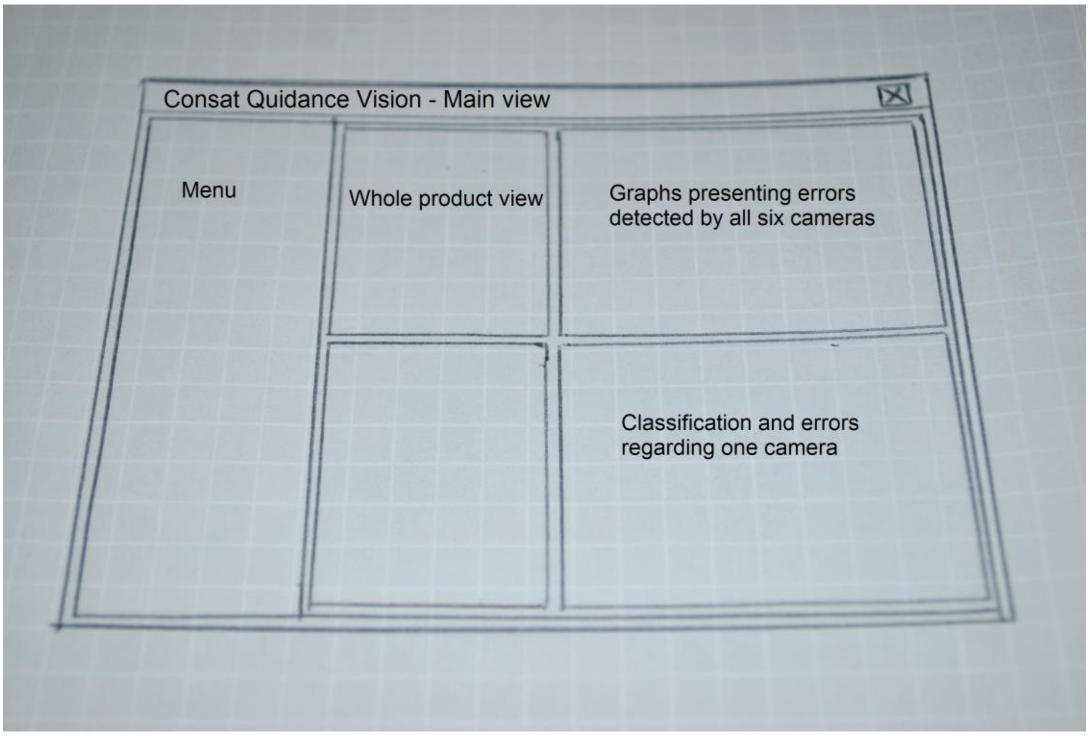

Figure 7-6 ***Main View*****, the start page.**

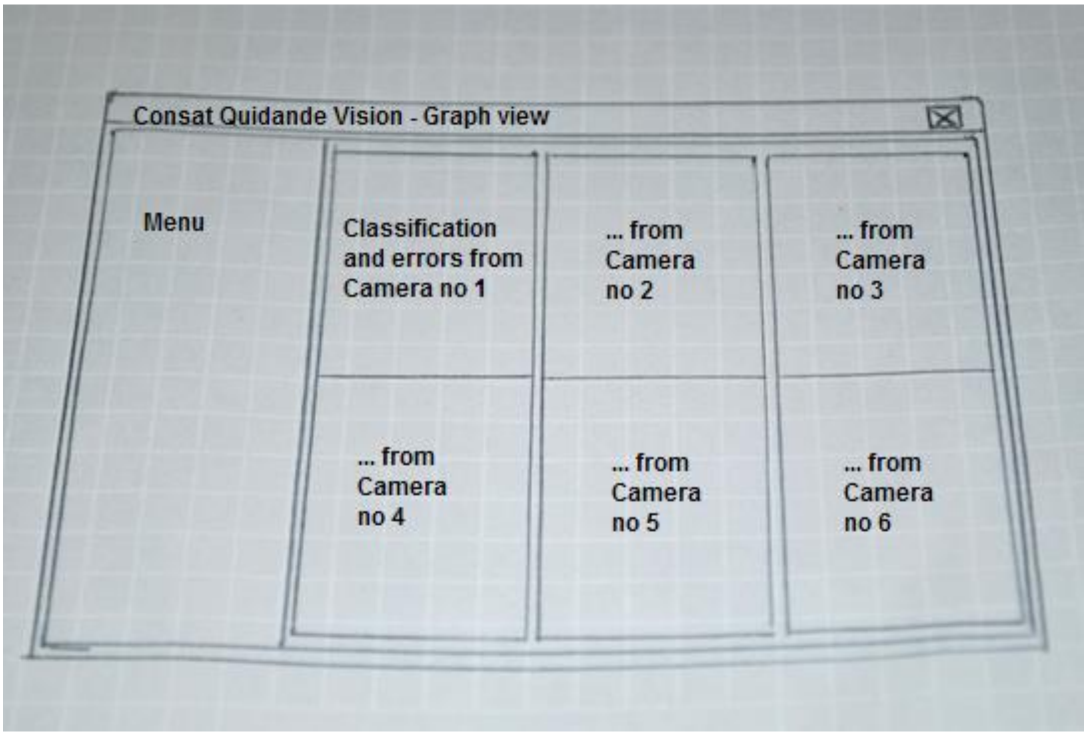

Figure 7-7 ***Graph View.***

The *Graph View*, *figure 7-7,* would give the user information from all six cameras. This view will have a graph setup, allowing the user to change the type of graphs presented. If it is possible to get variable data it would be possible to use *mean-chart* and *range-chart*.

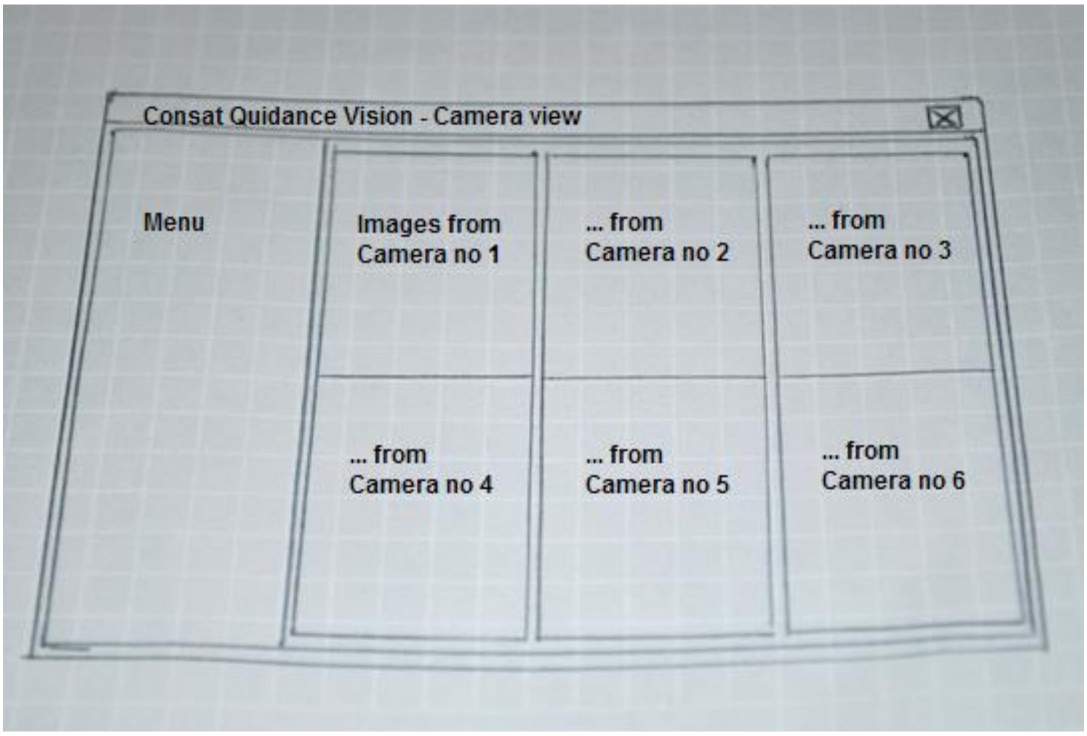

Figure 7-8 ***Camera View*****.**

The *Camera View* would be the new name of the start page of the current CQV interface, *figure 7-8*. This view will as well as in the current state presents all six cameras at the same time. The purpose of maintain the old view is due to the fact that the users are familiar with this view which most likely will contribute to that the new system would be easy to learn and usable at the very moment when implemented.

The last view, called *Analysis View,* will show detailed information regarding one camera. In *figure 7-9* an example of the layout of this view is presented. What to present should be developed together with the users in order to customize the view. In *figure 7-9*, is one example of where graphs can be presented.

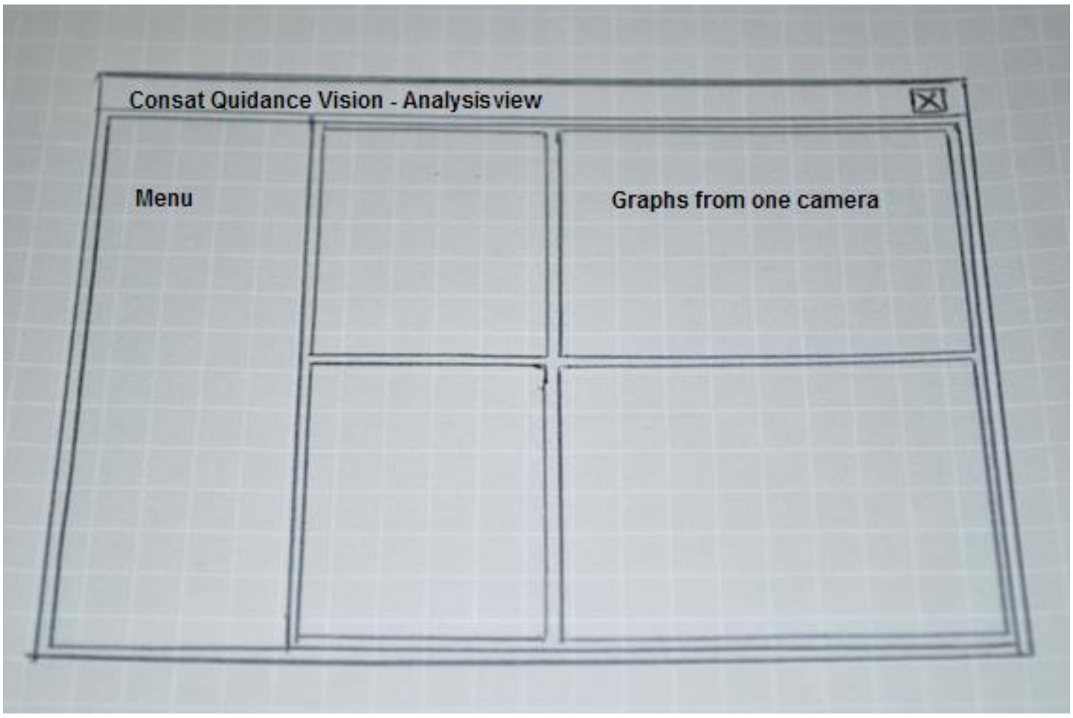

Figure 7-9 Analysis View.

Figure 7-10 presents the start page, the *Main View,* constructed in HTML. On the bottom to the left presents buttons in a 2x3 table which represent the 6 cameras named FW, LW, ET, AE, PO and LT. The buttons can preferably have 2 colours, red and green. The colours could express the state of the parameter. If the user clicks on one of the buttons, in *figure 7-10* FW is chosen, information from this camera will be shown in *Camera Info*.

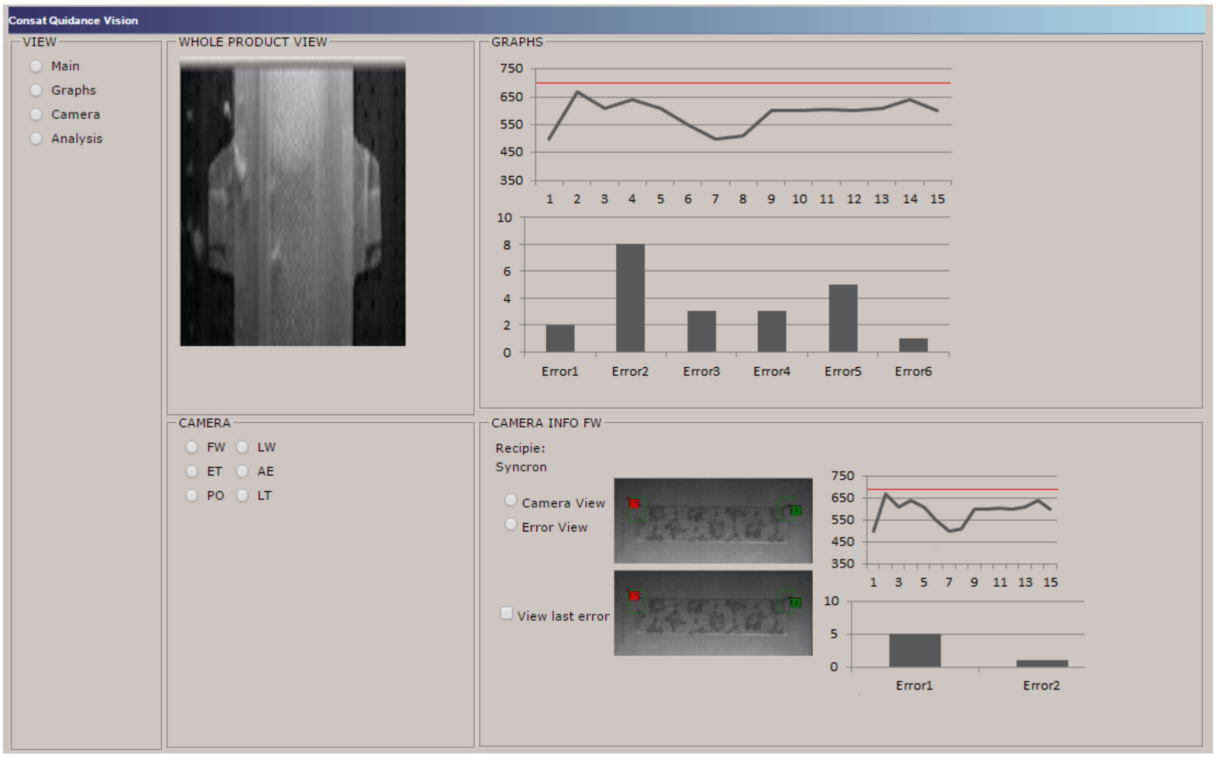

Figure 7-10 The main view constructed in HTML.

Additional functions

Based the results from the data collection alarms would preferably be sent to the operator panel based on the stakeholders' requirements.

Other features such as shortcuts could preferably be added, but that requires the developers to adopt those in collaboration with the users. Mouse roll over, when the mouse pointer is hold over an object, could be used to create a self-explaining interface that most likely will minimize the need for a user manual or major education in the implementation phase or when introducing it to new users.

A percentage representing the classification score could be presented in the bottom right corner at each image.

7.3. Comparison

The concept model include the standard view found in current CQV interface, the *Camera View* will represent this view. The general appearance of the interface will remain due to requirements but also to create a familiarity directly in the implementation phase. The concept model will enable an environment with alternatives, which allows the operator to choose a view suited for the situation. Let's say that the operator prefers information from all six cameras, the operator can use *Camera View*. If the operator instead wants all information presented as graphs preferably *Graph View* can be used. Or if the operator only wants an overview *Main View* can be chosen which should support the user with general information.

The goal with the concept model was to create an interface that supports the operators with information enabling them to take better decisions. The current CQV presents images, which will be maintained in the new design. New features will be classification score and presentation of graphs.

In *table 3* is the current CQV interface and the concept model compared against the statements found from the interviews.

Table 3 comparison of the current interface and the concept model.

Statements	**Current CVQ**	**Concept model**
Classification score		X
Present camera view	X	X
Additional features and graphs available		X
Whole product view available		X
Show graphs with limits		X
Send alarm to operator panel	X	X
Use commonly used production statistics		X
Highlight repetitive errors		X
The availability to present trends and patterns		X
Show most critical parameters		

8. Discussion

This chapter presents discussions regarding the data collection and analysis, the concept model as well as suggestions for further development.

8.1. Data collection and analysis

The participants interviewed in this project were recruited by recommendations from the determined representative at Company A. The snowball recruitment process allows the data collection to be based on opinions from a selected group. The fact that the researchers overall view of the distribution of the recruited stakeholder was limited may have contributed to a concept model only represent a small part of the beneficiaries at Company A. To avoid this more interviews with randomly selected participants at Company A could preferably be conducted together with a stakeholder analysis.

The notes collected at the interviews and observations were written by the researchers, which allow data to be interpreted by the researchers. The result could be that some data is lost due to the interpretation. The data collection showed that preconceptions on what the stakeholders may require and need was not always the truth. One of those preconceptions was that the operators most likely not were interested in graphs, which proved to be false. Some notes taken explain the need for further investigation, presented in *sub-chapter 8.3,* mainly the use of graphs, parameters and how to call for the operators' attention.

Regarding the list of statements, it is important to note that the quantity of each statement may be misleading and inaccurate. More interviewees might agree with the statements than the quantity number tells. This due to that the statements come from open questions and depending on what the interviewee expressed and found important in the very moment. The interviews were not aimed to ask direct questions related to others opinions.

Based on the problem definition of this project the beneficiaries were not predetermined and unable to be found before the analysis was done. No weighting or usability test with the identified beneficiaries was conducted.

The concept model should represent an interface that presents required information for the users. Exactly what the concept model views will present, for example which type of graphs the users prefers, was not included in this project. The concept model was not implemented neither validated by the potential users such as usability tests.

As a result a whole product view, score of classification and variable data is considered to be the sharpest requests from Company A, which should end up at the top of the list of what needs to be developed.

8.2. The concept model

The developed concept model should be able to meet its beneficiaries' wants and needs. Maintaining the current CQV´s general appearance and the standard view will give the operator alternative to explore other ways to find information and at the same time be able to find support in the old view. This will likely create a familiarity to the new system as well as minimize the cause of failure in the implementation phase, in comparison to if the system was newly conceived.

The concept model´s *Main View* presents more information than the old standard view. Instead of showing all cameras in one display, the thought was to have one image that presents the whole product.

As a recommendation, graphs should show defectives and score of classification per sample in a P-chart and a line chart, to serve the operator with a quick view in order to locate problems when they occur. If the classification method is changed and variable data can be achieved mean and range chart is preferred. In the view it is also possible to choose a view with more information regarding one camera this is done with a list (2x3 buttons). Specific information regarding one camera is available without the need for changing from the *Main View*. This study has a limit of stakeholders interviewed in the data collection and the selection of graphs may not be the optimal for all potential stakeholders. Theory supports the selection of graphs in this report.

The *Main View* presents an overview of the process quality, which will likely contribute to quick feedback for the operators in the operating the process. The overview will also enable to trouble shoot when information is shown on one display with P-charts that indicates which camera triggered the most errors.

Additional views were invented in order to serve the user with sufficient information based on the situation. If the user feel like it is important to see graphs connected to each camera on one display the *Graph View* can be chosen. This view presents graphs, no images, meaning that it can make it hard for the user to relate an error shown in the graph with the reality. To decide if this is a view that will be used by the user more interviews and studies will have to be conducted.

Analysis View should give the user a possibility to analyse the process. The thought was to give the user a tool to extract more information from the system. The view aims to help in trouble shooting or analysing the system during operating, both for operators and other beneficiaries. How and what to present is not included in this project. If this view should be developed it should be together with the user to achieve better usability.

The thought with presenting the score of the classification in every image is to give the user an indication of how reliable the decision was. Presenting the classification score in the picture gives easy access just by looking at the image.

Presenting graphs should enable easy and fast identification of where problems are located in the process. The graphs were chosen with respect to SPC, used at Company A. Educating the users in how to use this graphs would be recommended to minimize the resistance and explain how to use this graphs properly. The SPC graphs also give the possibility to see trends and send alarm if a deviation is found.

Sending the alarms detected by the CQV to the operator panel will continue, based on the results from the data collection. Presenting critical parameters were detected in the data collection but not included in the concept model due to the purpose of this project. This can be contributed with collaboration with the company to locate which parameters from the system that is in need to be presented.

8.3. Further development

The purpose of this project was to find development areas for the CQV platform related to production statistics and visualisation. The data collection confirmed that the CQV platform have development potentials, not only in the field of visualisation of production statistics.

The researchers found other areas towards a development of the current CQV. The identified needs at Company A were regarding monitor and collecting more parameters from the product but also from the process. Investigation what type of information the machine vision interface should express is something that will require further investigation.

The researchers would like to leave recommendations to the owner of the system to continue with this process and to further investigate the parameters presented in the list in *appendix B* to develop according to the customers suggestions. The data collection indicates that more areas could be monitored with vision both for the ability to predict and see trends but also to enable better control over the process. As a suggestion to the owner, CQV could implement more parameters in order to succeed with the trend identification. The current CQV will need further investigation in order to express trends and repetitive problems that satisfy the companies' requests.

The researchers recommend the future project of this development to be conducted together with the users. This will likely minimize confusion and resistance in the implementation phase. This project represents a foundation for further development of the CQV interface and platform. The researchers will give recommendation for future projects, to collaborate with the users and involve them early in the project in order to minimize the resistance. In the implementation phase will it be necessary to consider training and to provide demonstration of the new system.

The people involved in the data collection were positive to this development and had a lot of ideas in how to develop the CQV platform and interface to benefit the company. The researchers ended this project with sending out the documentation from each interview and observation to the participants, with the purpose to get feedback and comments on the documentation. The result was considered positive by the participants.

9. Conclusion

The result of this project defines that the CQV platform has development potentials not only in the areas of visualisation of production statistics from where the concept model was developed. The list of statements presents improvement potential areas and parameters aims to support future development projects of both the CQV platform as well as the interface. The areas of visualisation and production statistics were further used to create a specification of requirements. The specification of requirements was used as a foundation in the development of the concept model that presents production statistics in the CQV interface.

Qualitative and empirical studies were performed at three companies. Interviews were conducted at one company with stakeholders found via snowball recruitment. Two companies were visited and the result is presented in list of statements together with the results from the interviews.

The concept model presents a developed interface based on the stakeholders' opinions and literature review. The concept model aims to support the operators to take better decisions and perform on a higher level. The general appearance and the current standard view will be maintained in the concept model to create a familiar environment for the users directly at implementation.

Clearly the CQV platform has development potential. The researchers recommend the further researchers to develop the platform and interface together with the users and also to involve them early in the process. More investigation will be in need to define what to present in the concept model. The three companies investigated in this project were positive to the development of CQV and collaboration with the companies will most likely contribute to a sustainable development of the CQV platform and interface.

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A. Interview template

Headline	Questions and *sub questions*	Purpose
General	How long have you been working here? Your responsible areas?	Aims to find general information regarding the interviewees work tasks and background
Daily work	Manually performed tasks that preferably could be automated?	Aims to detect how they work and possible areas to improve related to their daily work.
Vision	Other areas where machine vision can be used? Do you think that there are limitations in the CQV system today? *Please explain how.*	Aims to find development potentials related to vision.
Statistics	What production statistics do you use/or can be found in your daily work?	Aims to find commonly used production statistics.
Problems	Which problems are repetitive? *Please explain them.* Are there any emergent problems? Do you find it important to have the possibility to predict problems?	Aims to detect most frequent problems.
Presentation	How would you like information to be presented on a screen?	Aims to find out how information preferably can be presented.

B. Sorted statements from the KJ analysis

List with abbreviations of all stakeholders found in the table below.

Company A
Q=Quality department
M=Technical Production Manager

P1=Process engineer 1
P2=Process engineer 2

ON=Novice operator x2
OE=Experienced operator

Company B & C
MB= Manager at Company B
MC= Manager at Company C

Owner of the system
X=Owner of the system

VISUALISATION	Stakeholder	Quantity
Compatible with CQV	X	1
Send alarm to operator panel	P2 OE	2
Show graphs in a separate tab	M P2	2
Show graphs with action lines	MC OE	2
Show actual-value when it moves from set-value	OE	1
Show the 20 most critical process parameters	M	1
Show where errors occurs	ON	1
Flexible and portable interface	MB	1
Highlight problems with light	MB MC	2

STATISTICS	Stakeholder	Quantity
Detect repetitive problems	P2	1
Commonly used statistics, SPC and Six Sigma	M	1
See trends	Q M P1 P2 MC	5
Collect warnings from operator panel	M	1

Alarm the operators before the process shuts down	M P1 ON	3
Find important parameters related to a certain problem	OE	1
Focus on statistics that can satisfy stakeholders needs and wants	X	1
Alarm if a process strives towards a limit	Q OE	2
Enable sufficient data for each department, and send out alarms to whom it concerns	MB MC	2

CQV	**Stakeholder**	**Quantity**
Improvement potential		
Variable data instead or as a complement to attribute data	Q P1	2
Use the *Blob* algorithm instead or as a complement to *Manto*	P2	1
Validation of CQV	P1	1
How to identify if reference images are in their right folder	P1	1
CQV is complicated/complex	P1	1
Score value of how well the product relate to an “ok” or “not ok” image	P1 P2	2
Store images for minimum 5 months, preferably 3 years	Q P1	2
No need for more software	P2 MC	2
Presents graphs of how well CQV classifies the products, the score value	P1	1
Backtracking availability	P2	1
Manto needs to be taught with images, *blob* can be used directly with units found in product specification	P2	1
Applications		
Application store	MB	1
Cloud based	MB	1
Self-developing	MB	1
Automatically adjust the process when CQV	MB	1

detect bad parameters		
Possibility to save all parameters related to one product, (backtracking)	MC	1
Hard to calibrate *Manto*, it needs to take good decisions for extreme cases and usual cases.	X	1

Data collection	**Stakeholder**	**Quantity**
Connect process and product parameters	M	1
Parameters from PLC	M P1	2
Save all error detections found in the operator panel at a certain time (when an error occur)	P2	1
Parameters from the process, ex. the adhesive pumps vacuum, revolution and pressure	Q M OE	3
Interface that enables information from other sources, ex. Codysys, Siemens and PLC to be shown	MB	1
Data type		
Raw data	Q MC	2
Compatible with other software	Q P2 M MC	4

MORE AREAS FOR VISION	**Stakeholder**	**Quantity**
Product related to Company A		
Gluing of the panels	Q M P1	3
Contour cut of the panels	P2 OE	2
Core, length, % of absorption material, lumps	Q M	2
Creases in material	Q	1
Image of complete product (whole product view), white light	Q M P1 P2	4
Image of complete product (whole product view), UV light	Q M P1 P2	4
Time stamp on product, plastic bag and carton	Q ON	2
Elastic threads exists	Q	1

Time stamp, synchronize the time stamp with the process/system	Q	1
Final packaging, look for holes and if sealing process that resulted in attaching the products in the process	Q	1
Adhesives attached at areas in the process, ex. at knives and other applications	P1 P2 ON OE	4
Automate manually performed measurements/tests	Q ON	2
Environment		
Monitor other areas such as counting human movements in a task	MB	1
Use vision to detect it the operators have performed a task in the right way	MC	1
Product related to Company C		
Surface quality	MC	1

C. Six Sigma

Description of DMAIC
Below presents the five phases and the methodology for the DMAIC.

Define
The define phase relates to the question “do we solve the right problem”. The key stage in the define phase is to discuss and find information to be able to adjust and negotiate the scope and resources. The purpose of this phase is to define relevant data such as customers, the scope and information to receive quality for the project. Then validate the problem definition and goal, and evaluate if the information received is important for the stakeholders, the business and if it is possible to improve with Lean Six Sigma (DMAIC) methodologies. Validate the financial benefits and if it is reasonably and if it meets management’s expectations (George et al, 2005).

Measure
In the measure phase should the process be expressed and mapped in order to be understood more in detail. To confirm the present flow a value stream map with data related to the process should be expressed. Evaluate if the inputs and outputs are relevant for this project and for these customers, and consider how to collect these data in a data collection plan. How the data analysis will be conducted needs to be planned, what methods will be used and what tools can be used. This can be modified during the project when the information is received. In the measurement step is it important to work with tools and procedures that are correct calibrated in order to get accurate, consistent and reliable data.

Collect data and update the value stream map with received information. To calculate the lead time Littles Law should be used. Next step is process capability evaluation in this step is it important to consider if long term or short term variations is used when calculating process capability, ask the data expert in the company what standards they are following. Obvious improvements can be implemented, but if the risks are high keep track of how this affects the system. Non-value-added process steps can be eliminated to improve the capability and time of the process (George et al, 2005).

Measurement System Analysis, Gauge R&R, Design of Experiments, Time Series Plots, are tool commonly used in the measurement phase. Some of them are described in the books written by Brook (2010) and Bergman and Klefsjö (2010). The mentioned measurement systems and charts are suitable for different type of data.

Analyse
The analyse phase includes finding improvements that is missing in performance in the current process. The key steps in analyse are finding value-added steps in the process, determine the improvement level, analyse the process flow, review the collected data from the measure phase and prioritize to find related parameters. In the last mentioned step can brainstorming or FMEA be helpful in order to prioritize the data.

Last step is finding additional data to verify the relationships found in the previous step and to prepare for the improve phase (George et al, 2005).

Improve

This phase involves the planning and test system towards the goal and final solution. The first step in this phase is to develop potential solutions, where statistical analysis can be used as a tool in the development. Next step is evaluation and selection of alternatives where Pugh matrixes and designed experiments can be used. In the design of a new system the criteria should be weighted in order to evaluate the alternative solutions. In this step is it Important to be open minded to new solutions and alternatives to find an optimal solution.

Further on, update the value stream map according to the developed solution and plan for a pilot test. The pilot test could involve simulation or sketches of the new system. Last steps involve comparison of the old and new system and the development of a full-scale implementation plan where a more detailed documentation needs to be performed (George et al, 2005).

Control

Last phase is to complete the project and deliver an improved process together with procedures for maintaining the improved process. In this steps could actions such as training and feedback from the developers in order to maintain the new system. Build in performance targets may contribute to that the users does not return to its old habits, this could mean empowering the users to improve the system. Feedback about the new system could be maintained with observations and interactions with the users.

Finally a complete documentation of the project including the teams comments, further development and lessons learned should be created, this due to contribute to further improvements and actions. Validation of the system should be conducted several months after the final implementation (George et al, 2005).

D. Statistical process control

Statistical process control, SPC, is not only a tool kit but also a strategy for reducing variability, cause of most quality problems, product variation, in times of deliveries, possible ways of doing tasks, in material, attitudes, equipment, maintenance, everywhere in a systematic way.

Everything in an organisation can be counted as a process, which (Oakland, 2008):

- requires understanding
- has variation
- must be properly controlled
- has a capability
- needs improvements

Process Understanding

A process is a transformation of inputs into outputs. The inputs can be material, methods, information, equipment, environment, training or knowledge. While the output can be a product, service, information or documents. Meaning a function in an organization can be many processes taking place at the same time. Each process should be individually analysed by an examination of the inputs and the outputs. This will give a clear picture of necessary actions to improve quality (Oakland, 2008).

When a process is supposed to be monitored and analysed. The first is to identify what the process is and which inputs it has as well as outputs. Many processes are easy to understand. Example, also illustrated in *figure D-1*: drill a hole, filling cans or compress tablets. But not all processes are easy to understand, for example customer service, storage of a product or inputting process to a computer. It is essential to make a scope of a process, since it will determine not only the needed inputs but also the resultant outputs.

When the process is specified it is possible to create SIPOC stream (Oakland, 2008). A SIPOC diagram is commonly used early in the design phase to write down important information and basic elements, this to be able to maintain a high level of quality in the process. This is a way to create output requirements from customer requirements (George et.al, 2005). The inputs to the system are all required resources to make the process possible.

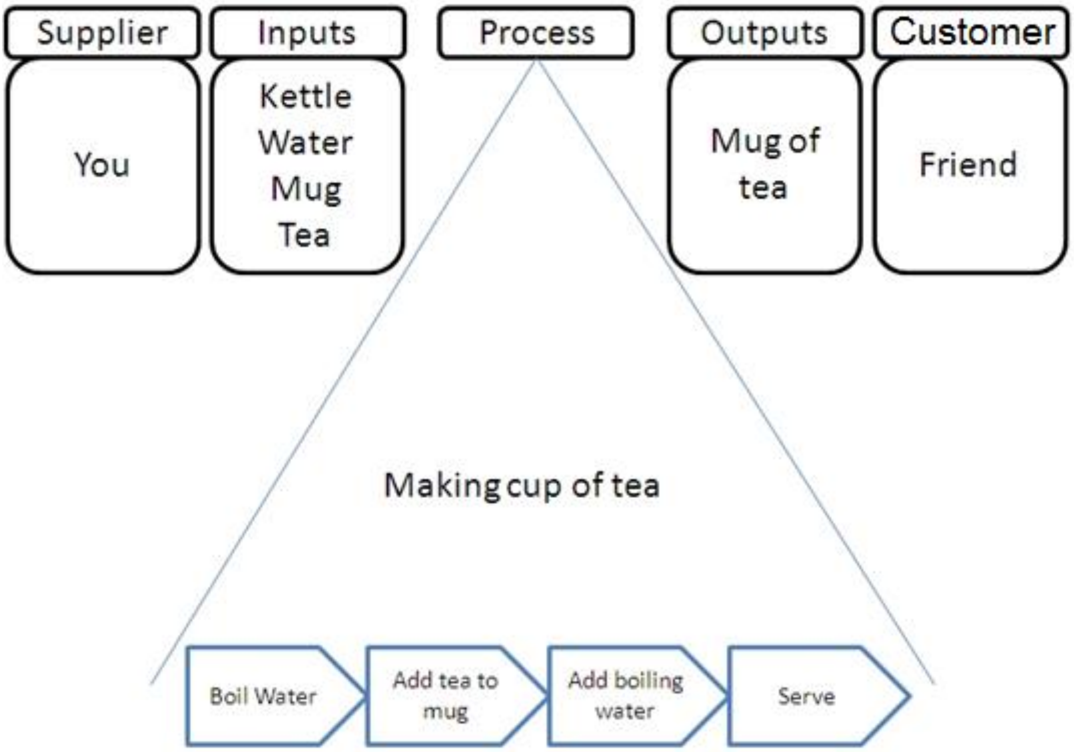

Figure D-1 Description of a SIPOC stream when serving your friend a cup of tea.

To prevent a failure in any transformation it is important the process is defined, inputs and outputs are properly documented but also determined. An extensive documentation will allow reliable data from the process to be collected and analysed. From this actions to improve the process and prevent failure can be preceded (Oakland, 2008).

A systematic study of a defined process through answering four questions (Oakland, 2008, CH 1.3, PP 17):

- Can we do the job correctly? (capability)
- Are we doing the job correctly? (control)
- Have we done the job correctly? (quality assurance)
- Could we do the job better? (improvements)

Variation

Each process has a variation. The variation can in many cases be hard to explain. Take a sales department at a company, one month the sales outperform their target and the next month they do not even fill half of their goal. Why?

In a production the system is "*in statistical control"* or "*stable*" if and only if common cause is presented in a process, common cause could be traffic problem, operator performance or weather, variations unable to control. Sales figures can be a result from common causes of variations due to the buyers´ physical and emotional variation (Oakland, 2008).

There is also a variation with relatively large magnitudes and often readable. This variation is called special variations. If the process has this variations the process will be "*out of statistical control*" or "*unstable".*

The following two questions should be answered to receive an understanding if the process is possible to meet the question "*Can we do this job correctly?"* (Oakland, 2008):

- *Is the process in control?* - Are special causes of variation present?
- *What is the extend of the process variability?* - What is the capability when only common causes of variation are present?

This approach can be applied to both attribute data and variables. It provides a systematic methodology to examine, control and investigate a process. The variation can be showed in a schematic control chart. Where the upper and lower control limit will be equal to the biggest accepted variation (Oakland, 2008).

Control

All too often processes are adjusted after just a single measurement has been performed. Even if the process is stable it still occurs random and common causes of variation making a one sample adjustment not sufficient. Oakland (2008) argues that it is essential to take 4 to 12 samples to provide sensitivity which can detect a change of the mean of the process. From this a suitable corrective action can be taken. If a sampling size is larger than 12 the range value will lose efficiency due to the values in between highest and lowest are not presented.

Data collected as variables is presented in a mean and range chart, presented in *figure D-3* respectively *figure D-4*. This makes it possible to see if the $\overline{X}$ (sampled mean value) lies in the range $\pm 3\sigma$. If the process is stable this should be the case. If $\overline{X}$ is in a rising or falling trend relative to the process mean the process needs to be adjusted, this yields also when $\overline{X}$ is below or above process mean. The process mean is the calculated mean value for the process.

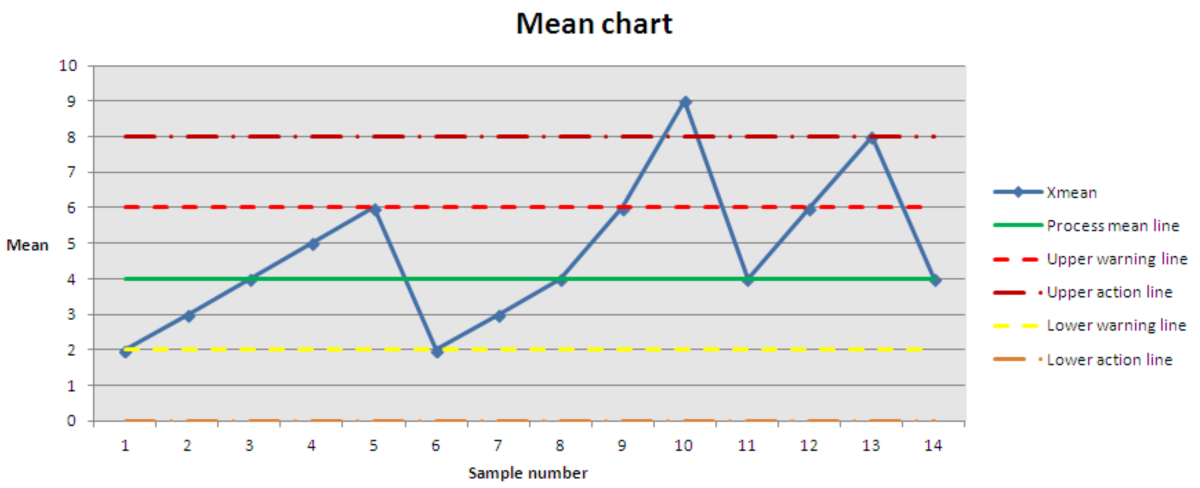

Figure D-2 Mean chart.

In the mean chart there are upper action, upper warning, process mean, lower warning, and lower action line at:

- Process mean line : $\bar{\bar{X}} = Average\ of\ \bar{X}$
- Upper action line: $\bar{\bar{X}} + \frac{3\sigma}{\sqrt{n}}$
- Upper warning line: $\bar{\bar{X}} + \frac{2\sigma}{\sqrt{n}}$
- Lower warning line: $\bar{\bar{X}} - \frac{2\sigma}{\sqrt{n}}$
- Lower action line: $\bar{\bar{X}} - \frac{3\sigma}{\sqrt{n}}$

where $\sigma = \frac{\bar{R}}{d_n}$ and d_n is Hartley´s constant. $\bar{R}$ is the mean range of a sample and n is the sample size (Oakland, 2008).

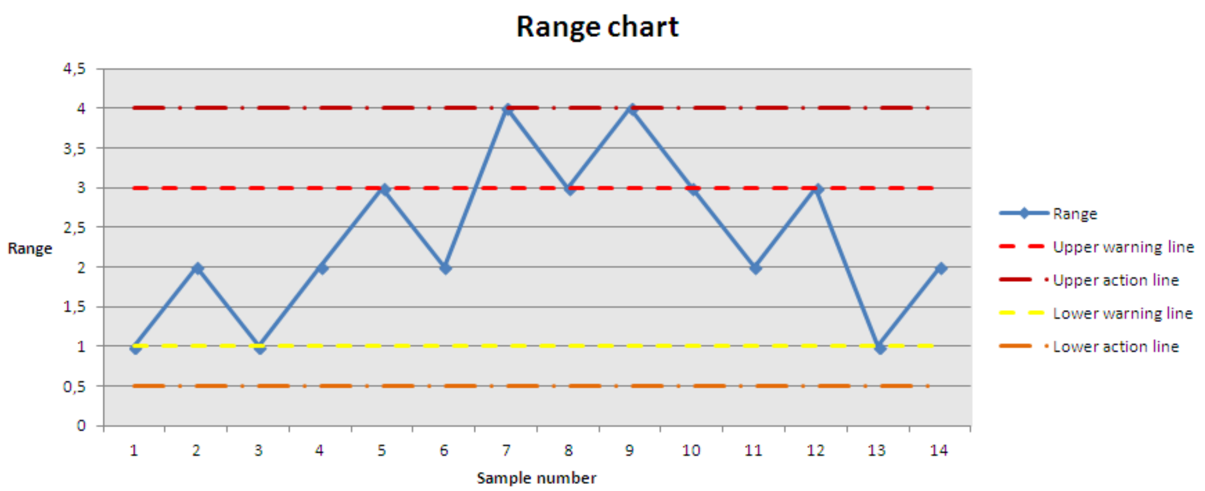

Figure D-3 Range chart.

In the range chart action and warning lines are not symmetric due to range only can be 0 or higher and will instead be:

- Upper action line: $D_{0.001}\bar{R}$
- Upper warning line: $D_{0.025}\bar{R}$
- Lower warning line: $D_{0.975}\bar{R}$
- Lower action line: $D_{0.999}\bar{R}$

If the process is in control:

- No mean or range values outside the action limits
- No more than 1 in 40 values between warning and action limits
- No case where two mean or range values lies after each other outside the same warning line
- No runs or trends of five or more which is in the warning zone or action zone
- No runs where more than 6 sample means lies either above or below the process mean.
- No more than 6 samples of the mean being in a rising or falling trend.

Attribute

Collected data in forms of attributes, or in other term Booleans, makes it impossible to use mean and range charts to control the process. There are two types of control charts to control a process when having attribute data (Oakland, 2008):

- Number of defectives chart
- Number of defects chart

The Defectives chart with constant sample size is called np-chart, with samples of varying size it is called p-charts. Defects chart with same size of sample every time is called c-charts and with varying sample size called u-charts. Np-chart is used when there is possible to maintain a constant sample size.

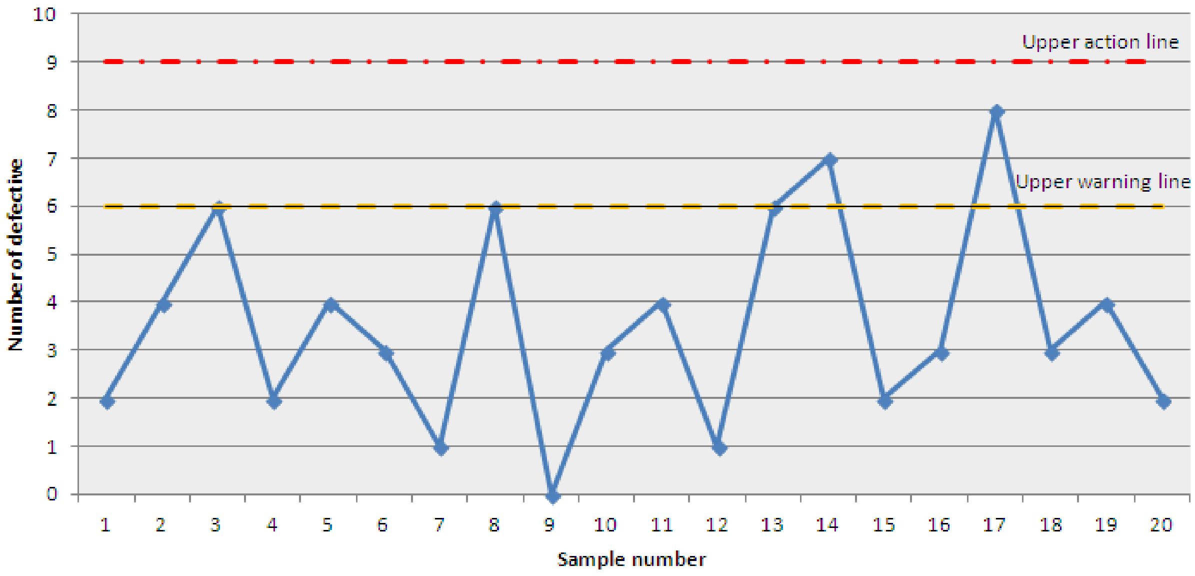

Figure D-4 np-chart.

The goal with np-charts, *figure D-5*, is to present the defectives in a constant sample size *n.* The centreline is $n\bar{p}$, warning lines $n\bar{p} \pm 2\sqrt{n\bar{p}\,(1-\bar{p})}$ and the action line is $n\bar{p} \pm 3\sqrt{n\bar{p}\,(1-\bar{p})}$ is the proportion defective, $\bar{p}$ is average value of *p* (Oakland, 2008).

When it is impossible to maintain constant sample size *n* a p-chart, *figure D-6*, may be used. It is similar to np-chart but instead of having constant upper action and warning lines moving depending on the sample size.

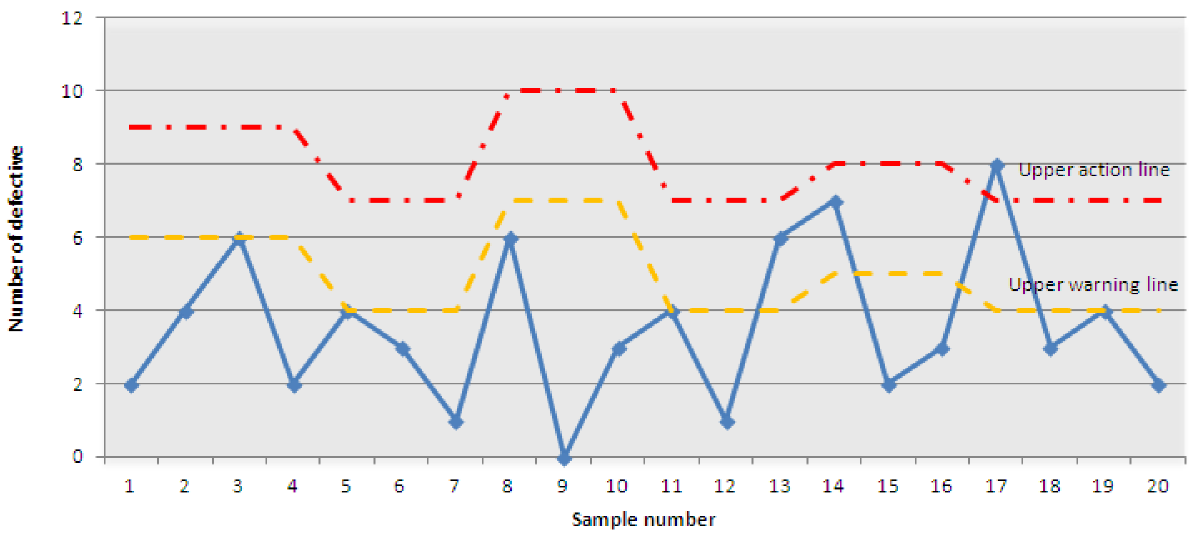

Figure D-5 p-chart.

The p-chart has a centreline $\bar{p}$, warning lines $\bar{p} \pm 2\sqrt{\bar{p}\,(\frac{1-\bar{p}}{\bar{n}})}$ and an action line $\bar{p} \pm 3\sqrt{\bar{p}\,(\frac{1-\bar{p}}{\bar{n}})}$. $\bar{n}$ is the average sampling size. Note, holds only if *n* is in zone ($\bar{n} \pm 25\%$) (Oakland, 2008).

Capability

When a process is in statistical control, do not have any special causes of variation present. It is possible to investigate if the process capability meets the requirements. This can be done by comparing the tolerances against the variation in the process.

If the tolerance band is wider than the variation, the process has medium to high relative precision. While if the tolerance band is less than the variation, the process has low relative precision (Oakland, 2008).

A relative precision index (RPI) can tell if a process has the capability to meet the tolerances.

$$RPI = \frac{Tolerance\ range}{\bar{R}}$$

$$RPI_{minumun} = \frac{6}{Hartley\acute{}s\ constant}$$

if $RPI > RPI_{minumun}$ the system has capabilities to meet the tolerance requirements (Oakland, 2008).

Cp index can also be used to find the capabilities of the process. If the Cp index is greater than 1 the process has capability (Oakland, 2008).

$$Cp = \frac{(Upper\ specification\ limits - Lower\ specification\ limits)}{6\sigma}$$

If the process is not centred, the mean is not in the middle of USL and LSL, Cp index cannot be used. Instead Cpk index can be used to tell the capabilities of the process.

$$Cpk_u = \frac{USL - \bar{\bar{X}}}{3\sigma}$$

$$Cpk_l = \frac{\bar{\bar{X}} - LSL}{3\sigma}$$

If they are greater than 1 the system has capability, but it is has high level of confidence first when it is greater than 2. This yields also for Cp index (Oakland, 2008).

Improvements
SPC recommends the methods using fact rather than feelings when doing improvements. It includes the never ending improvements cycle plan, do check and act, PDCA. This approach focuses on suppliers, inputs, control, resources but exclude the output (Oakland, 2008).

Other methods are pareto analysis, cause and effect analysis but also brainstorming with affected employees can help to find new improvements. A scatter diagram can be used to highlight relationships between factors. A commonly used improvement method is the Six Sigma Define, Measure, Analyse, Improve, and Control (DMAIC) (Oakland, 2008).

Basic tools of SPC
In SPC information and numbers will form the basis for actions and decisions. Therefore a data recording system is essential. To support the management system with a framework for recording data. It exist a set of basic tools which may be used to derive maximum use of the data. In the list below a set of tool to give any organization possibilities to collect, present and analyse most of its data (Oakland, 2008, CH 1.4, PP 18):

- Process flowcharts - What is done?
- Check sheets - How often is it done?
- Histograms - What does the variation look like?
- Graphs - Can the variation be represented in a time series?
- Pareto analysis - Which are the big problems?
- Cause and effect analysis - What cause the problems?
- Scatter diagrams - What are the relationships between factors?
- Control charts - Which variations to control and how?