Traceability in a Sanitary Ware Production System
– A Case Study at Ifö Sanitär

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Preface

This Master Thesis was performed at the Faculty of Engineering at Lund University as the final part of our Master of Science in Mechanical Engineering during the spring of 2013. It was performed in collaboration with Ifö Sanitär AB, which had identified the need for better traceability and production reporting at the factory in Bromölla.

This project has been a great experience and learning opportunity for us. In this 20 week long project we applied many of the things we have learned during our specialization in the field of production management and logistics.

First of all we would like to thank and acknowledge our supervisor Johan Bergskans at Ifö Sanitär for the invaluable support during this project. We would also like to thank the steering group at Ifö for their commitment and valuable insight to this project.

We would also like to thank our supervisor at the Division of Production Management Bertil I Nilsson for his feedback and guidance during this project.

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Abstract

Title:	Traceability in a Sanitary Ware Production System – A Case Study at Ifö Sanitär
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Research questions:	How to implement a traceability system in an automated sanitary ware production system
Deliverables:	This thesis establishes whether it is cost beneficial to implement a traceability system for an automated sanitary ware production system where there are no legislative requirements.
Methodology:	The research method that is used in this thesis is a combination of action research and experimental methods. A literature review, observations and interviews were performed in order to identify existing traceability theories and applications as well as fully understand the production characteristics of sanitary ware manufacturing. In addition, experiments were performed in order to evaluate the most suitable traceability application for the use in an automated sanitary ware production system.
Delimitations:	This thesis covers the use of traceability and its applications in the automated production lines at Ifö's factory in Bromölla and it only includes the internal flow of goods at Ifö.

Conclusions:	The solution includes a direct part marking on each and every product that is produced in Bromölla, with an individual serial number. All product movements will be stored, allowing for the ability to conduct follow-ups on defects and performance of different parts of the production system. It can be concluded that the use of an automated traceability system is cost-beneficial in the automated production lines at Ifö Sanitär.

Keywords:	Traceability methods, traceability system, sanitary ware production, marking on ceramics, continuous improvement, AIDC

Acronyms and glossary

AGV	An **Automated Guided Vehicle** is a self-propelled robot that follows markers or wires in the floor, or uses vision systems or laser for guidance
AIDC	**Automatic Identification and Data Capture**
Binary code	Represents text or computing instructions using the binary systems two digits 0 or 1, meaning “ON” or “OFF”
Demolding plate	A tool that the piece rests on after the casting glazing operation
Dried ware	A piece that have been casted and dried
ERP	An **Enterprise Resource Planning** system keeps track and stores all relevant business information across an organization such as financial information, purchasing, manufacturing, sales, customer information etc.
FFC	**Fine Fire Clay**
FIFO	**First In First Out**
FMEA	**Failure Mode and Effect Analysis** is a tool for failure analysis and is used for quality improvement
Glaze	Glaze is a layer of vitreous substance that fuses with a ceramic object during firing. It serves to color, strengthen or waterproof an item
Glazing plate	A tool that the piece rests on after the casting and during the glazing operation
Green ware	A piece that have been casted, but not dried
LEAN	A manufacturing philosophy that considers expenditure of resources other than for creating value for the end customer as wasteful, and must therefore be eliminated

LIFO	**Last In First Out**
OEE-system	**Overall Equipment Effectiveness system** evaluates how effectively a manufacturing operation is utilized
PDA	A **Personal Digital Assistant** is a handheld computer
VC	**Vitreous China**
WIP	**Work In Process** are products that are currently in the production process

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1 Introduction

The introduction deals with a short description of traceability, an introduction of the company and the factory where the project is carried out. A problem description for the project is also included and the delimitations. This information leads to the purpose of the project. Project deliverables and reading instructions are also included.

1.1 Traceability in general

van der Vorst (2006) has defined traceability as “The ability to document and trace a product (lot) forward and backward and its history through the whole or part, of a production chain from harvest through transport, storage, processing, distribution and sales.” In order to keep a general approach the word lot is used. The amount of distinct items is not set and can vary from one to multiple. The need of better traceability in businesses have increased in the last decades, especially in the food industry due to certain events like the outbreak of mad-cow decease in the 80’s and 90’s, and foot-and-mouth decease in the 00’s. These events led to that the general public demanded information regarding what had been produced where and when. There were also problems with the recall of infected meat, the producers could not locate to which locations the infected meat had been distributed (Kvarnström, 2010).

Traceability can be used in many applications but the most obvious one is in logistic applications, for example, in order to track and trace a certain product that has been packed at a certain point in time. It is also an important tool in order to support LEAN in businesses i.e. supporting the work of continuous improvements due to an increased ability to find root causes (Mahoney & Thor, 1994, cited by Kvarnström, 2010). If a company wants to be ISO9001-2008 certified it needs to be able to on demand show traceability either internally or to a third party (International Organization for Standardization, 2008).

The use of traceability differs a lot depending on what industry that is highlighted. The food industry and the pharmaceutical industry are known for their extensive traceability, this is however rather forced upon them due to legislation. There are also industries where the traceability is well developed even though legislation does not force them to. The automotive industry is an example where the LEAN principles are extensively implemented and in conjunction with that the traceability is needed in order to minimize waste and to continuously improve. There are no legal demands on the sanitary ware industry, the demand for traceability is stated in the ISO9001-certification, and required by the customers. There are suppliers of both marking methods and IT-systems that provide solutions for extensive traceability that are specialized in the sanitary ware industry. These solutions are developed with a non-automated situation in mind, where the marking of the pieces are carried out manually (S.A.I.T. S.R.L., 2009).

1.2 Company background

Ifö Sanitär AB, from now on Ifö, is the Nordic market leader of sanitary ware and kitchen sinks. They are part of the Finnish Sanitec Corporate Group, which is the leading European multi-brand bathroom ceramics specialist. Ifö's business concept is to provide an all-inclusive range of products for bathrooms and toilets along with kitchen and utility sinks. Except for the Nordic region Ifö also conduct business operations in Russia and in the Baltic region. Ifö currently employs approximately 560 people and the annual turnover for 2011 was 1 287 099 000 SEK. There are two production plants active in Sweden, both situated in the south. The largest one is situated in Bromölla and it handles all types of sanitary porcelain. The second plant is located in Mörrum that mainly produces bathtubs and showers, and no ceramic products.

1.3 Background of the facility in Bromölla

Since 1936 water closets have been produced in Bromölla. The raw material that was used, lime and china clay, was collected from the nearby small island, Ivön. For 65 years the operations were handled manually to a large extent, until 2003 when substantial investments were made in order to automate the production. A state-of-the-art pressure casting technology was implemented and in addition to that, an implementation of lean principles was made. These changes have given Ifö an edge against the competition and have made the factory the most efficient one in the Sanitec group.

1.4 Problem description

During the last few years there has been an increased discrepancy in the internal warehouse stock account at Ifö in Bromölla, which has triggered the need for better traceability through the production. All of the production reporting is performed manually, which in some cases results in faulty inputs due to high work intensity. Therefore, Ifö desires to automate the production reporting to decrease the amount of faulty inputs.

The Ifö quality system also requires a traceability of the products, which today is deficient because there is no easy way of determining when a product has been made. This becomes more complicated with the water closets, since they are made from multiple components that can have been produced at completely different points in time. The traceability needed for dealing with customer claims is lacking, consequently the management at the factory in Bromölla believes that a lot could be gained by improving the traceability at the factory. There are no legal requirements for traceability in the industry Ifö operates in, and the need of extensive traceability is purely driven by the factory’s desire to improve their operations.

There have been discussions for a long time regarding the possibility to implement better traceability in the factory, and now the management would like to ascertain the potential for such an implementation. This would include how to implement a system as such as well as integrating it to the highly automated production system, which means that all, or as many as possible, of the activities regarding the traceability system should be handled automatically. The requirements of the production system are to be taken into consideration when implementing a new system in order to achieve an as smooth transition to the new system as possible. Since the management of the factory drives the need of improved traceability, the investment in such a system also needs to be analyzed in order to determine if it is cost-beneficial to implement it.

1.5 Delimitations

The project will only focus on the factory in Bromölla. It will cover the material flow from when the raw material enters the factory until the product is installed at the end customer. The low quantity production line with manual casting is excluded from the project. The project will not make changes in the material flows in the factory unless the steering group sanctions them.

1.6 Purpose

The purpose of this thesis is to investigate how to implement a product traceability system in Ifö's factory in Bromölla, and how to integrate automated production reporting with their current ERP-system or with a standalone system. A specification of requirements is to be established both for the marking method and the traceability system as a whole. This will be carried out in order to find the most suitable marking method and to fit the traceability system in a satisfying matter in the production system. It is also required to establish whether it is cost-beneficial to implement a traceability system in a production system, where the industry that does not have certain regulations or requirements from their customers regarding extensive traceability.

1.7 Project deliverables

The main deliverables of this thesis is to establish whether it is economically beneficial to improve the traceability by introducing a product marking system in the Bromölla factory. Furthermore, identify the most suitable automated product marking method and a system for automatic registration of approved items when they are moving to the next process. These two parts will be handled in a technical report that is meant for the academy. In accordance with this report a separate summary will be written in the form of a popular science article and a seminar will be held. As for the company, a 30-minute presentation will be held for the senior management at the factory, and if the investment is deemed profitable with a payback time of three years, an investment demand is to be written.

1.8 The structure of the report

This subchapter will supply the reader with enough information to get a clear view of how the report is structured and to understand how the chapters are connected to the purpose of the project. It should be noted that the structure of the report is not related to how the project have been conducted. The structure used in this report has been chosen in order to simplify the understanding of the project for the reader. A summary of how the work has been conducted can be found in subchapter *2.1.6* Research strategies in this thesis.

1.8.1 Introduction

The introduction includes a short presentation of the company where the project have been carried out, a presentation of what traceability is in general and some applications, a problem formulation for the project at hand, and the delimitations of the project. The information supplied in the background should be sufficient in order for the reader to understand why all the subparts of the purpose are needed for the project.

1.8.2 Methodology

This chapter is to be read in order to understand how the authors have conducted the project in order to satisfy the purpose. Different approaches are discussed and the authors' choice of approach is also presented to the reader.

1.8.3 Frame of reference

The frame of reference should be read if the reader wants to know what research and general information regarding traceability that was available to the authors to use in the project. The information presented in this chapter is applied on the highlighted production system and is crucial in order to satisfy the purpose of the project. The chapter deals with the structure of a traceability system, the technologies associated with automatic identification and data capture (AIDC), and the design and implementation of the system.

1.8.4 Empirics

This chapter will supply the reader with sufficient information regarding the production system at Ifö in Bromölla needed to draw conclusions for a traceability system. In addition to that the flow of goods from raw material to end-customer and the claims handling of Ifö's own brand is explained. The information supplied in this chapter is especially important in order for the authors to identify the needs of the production system, in order to develop a specification of requirements for the traceability system and the traceability method.

1.8.5 Experiments

The experiments chapter should be read as a stand-alone chapter where marking methods from subchapter *3.5.4 Marking methods* are tested and evaluated. This chapter focuses on the application of different marking methods and the reliability of them after the different process steps. The reader should note that these experiments are not directly quantifiable, but rather an example of what works, and how good it works, for the specific conditions at Ifö's production lines.

1.8.6 Analysis

In the analysis the frame of reference, chapter *3*, is compared against the current situation, found in the chapter *4 Empirics.* In addition to this comparison, aspects discovered during the mapping of the production system are discussed. This chapter is meant to guide the reader into the following chapters *7 Specification of requirements* and *8 Proposal and alternatives,* the reasoning behind the specifications and the proposal can be found in the analysis.

1.8.7 Specification of requirements

This chapter aims to give the reader a specific knowledge of the technical requirements for both the traceability system and the specific AIDC method. This chapter is based on chapter *5 Experiments* and *6 Analysis* and should be read as a prerequisite in order to understand why the proposal and alternatives in chapter *8 Proposal and alternatives* has been made.

1.8.8 Proposal and alternatives

In this chapter the main proposal and the alternatives are presented with a cost-benefit analysis and investment appraisal. The reader should be able to evaluate these proposals with the preceding chapters in mind.

1.8.9 Conclusion

In this chapter, the authors aim to summarize the outcome of this thesis and give the reader follow-up on the purposes of this thesis mentioned in subchapter *1.6 Purpose.*

1.8.10 Implementation plan

In this chapter a short implementation plan is presented and aspects to consider are brought to attention. This chapter is primarily directed to personnel at Ifö.

1.8.11 Additional work

This chapter describes how the traceability system can be further expanded and what possibilities of business improvements it brings.

1.8.12 Discussion
The aim of this chapter is to analyze the value of the thesis and to give the reader further information on the impact the traceability system will have on several parties within Ifö.

1.8.13 Contribution to the academia
In this chapter the authors establishes how this thesis can contribute to the academia by comparing the existing literature to the work in this thesis.

2 Methodology

In this chapter different research strategies, research methods, methods for gathering data, approaches, procedures for analyzing and drawing conclusions, and thesis value will be discussed. Several alternatives will be presented and the methodology chosen by the authors is motivated.

2.1 Research strategies

2.1.1 Exploratory

An exploratory study aims to give an in-depth understanding how something functions or is executed (Höst, et al., 2006, p. 29). The exploratory strategy is often used when there is little to no knowledge about the subject. It is used to obtain more information and establish the relevant issues to investigate (Lekvall & Wahlbin, 2001, pp. 196-197).

2.1.2 Descriptive

The main purpose of a descriptive study is to find out and describe how something functions or is executed (Höst, et al., 2006, p. 29). It does not try to explain *why* something occurs but rather *how it looks like* (Lekvall & Wahlbin, 2001, p. 197). A descriptive study is well defined and delimited before it commences and tends to a large extent to be based on measurements and quantitative methods. The study provides knowledge about different connections and relations. However, the study can never prove that a certain variable affects the other (DePoy & Gitlin, 1999, pp. 102-103).

2.1.3 Explanatory

An explanatory study seeks causation and explanations to how something functions or is executed (Höst, et al., 2006, p. 29). This type of study often has high demand for statistical certainty that puts high demand on the methodical and technical approach (Lekvall & Wahlbin, 2001, p. 197). Explanatory studies are based on an accepted theoretical framework and the purpose is to support the theory. These studies are solely based on measurements and statistical analyses of quantitative data (DePoy & Gitlin, 1999, p. 103).

2.1.4 Normative

The purpose of a normative study is to find a solution to a specific problem that has been identified (Höst, et al., 2006). It is used when the project group already has knowledge in the area. The goal is to provide guidance and propose actions (Björklund & Paulsson, 2003, p. 58).

2.1.5 Predictive

A predictive study results in a prediction or a forecast for a future development. In order to understand why a system behaves in a certain way, knowledge must be acquired beforehand. The understanding is crucial in order to credibly forecast the future development (Lekvall & Wahlbin, 2001, pp. 197-198).

2.1.6 Research strategies in this thesis

The internal processes of this thesis are not widely known at the start of the project. In order to get an idea of what is needed and to obtain more information an exploratory approach will be used for the first couple of weeks. During this phase a lot of time will be spent compiling the literature on the subject. Initial interviews with key staff members will also be carried out during this period in order to get an initial understanding of the production system.

After a reasonable knowledge base has been built, the study goes into the descriptive phase. The production line that the study mainly was focused on will be mapped in order to get a solid base to stand on when different traceability systems and traceability marking methods were analyzed. Additional literature studies will be carried out in accordance with what is discovered during the mapping of the production line.

When a wide knowledge has been attained both of the production system and traceability in general, the thesis will go into the third phase, explanatory. In this phase experiments with different marking methods will be carried out in order to find out if they can be adapted into the production system. During this phase the benefits with traceability will be covered and compiled in order to support an investment demand. The approach can be found in *Table 1*.

Table 1 – Research strategies in this thesis

Phase 1: Exploratory	**Phase 2:** Descriptive	**Phase 3:** Explanatory
Activities: Initial literature studies Interviews with personnel vital to the processes Interviews with personnel at the production stations Direct observations	**Input:** General specification of requirements General knowledge of the production system	**Input:** Possible traceability methods and suppliers, chosen for tests Considerable knowledge in the production system
	Activities: Additional literature readings Mapping of the production system through observations and validation through interviews Customize the specification of requirements in accordance with the production system's needs, see chapter *7 Specification of requirements*	**Activities:** Carry out experiments on possible traceability methods Identify benefits with traceability that can prompt cost savings, and quantify these through surveys, interviews, and observations
Focus: Explore processes, traceability systems and traceability methods	**Focus:** Understand processes and dig deeper into fitting traceability systems and traceability methods	**Focus:** Find the most suitable system and method of traceability for the production system. Connect resolved issues with monetary values
Deliverables: General specification of requirements for the traceability system and the traceability method	**Deliverables:** Requests of information sent out to suitable companies in the AIDC industry General "ideal" solution for a traceability system, see subchapter *7.3 Concept for the standard washbasin production line*	**Deliverables:** Proposal regarding marking method and traceability system, see chapter *8 Proposal and alternatives* Cost-benefit analysis regarding the implementation of a traceability system, see subchapter *8.2 Cost-benefit*

2.2 Research methods

2.2.1 Desk research

Desk research means that the project group ”reanalyzes” one or several data collections that have been carried out earlier in other projects. The purpose of this analysis is to raise different questions than those that were raised the last time (DePoy & Gitlin, 1999, p. 236).

2.2.2 Survey

A survey is a compilation and a description of the current status of the studied object or phenomena. Often, the purpose of the survey is to describe a broad question. The survey is performed by using quantitative data and/or qualitative data gathered by questionnaires and interviews drawn from a random sample of the population that is supposed to be studied. Therefore, once a protocol has been set up and sent out it must remain the same. No questions can be altered throughout the process. A survey is used not only to describe the current status but also to predict factors that can lead to satisfaction. The benefit of using a survey is that a large amount of persons can be reached with a relatively small effort. However, the drawback is that depending on the way it is distributed, a survey can get a low response rate (DePoy & Gitlin, 1999, p. 149).

2.2.3 Case study

A case study is an in-depth study of one or several cases where the researcher tries to minimize his influence on the studied object. A case study often describes a specific case which is often chosen for a specific purpose. Therefore, no generalizations of the results are made for other cases. A case study can, for example, be made within an organization in order to understand how they work. Case studies can include both quantitative and qualitative data. It can be limited to one case or include several cases as well as being exploratory, descriptive or predictive. Case studies are suitable when a phenomenon should be studied in its natural environment, if it should contribute to or develop a theory or if a case that is non-typical or different needs to be explored thoroughly (DePoy & Gitlin, 1999, pp. 192-193).

2.2.4 Experimental

A comparative analysis of multiple alternatives where the parameters are identified and one or multiple parameters are altered. This is done in order to find causation with the purpose to explain why a certain phenomenon occurs. An experiment is a fix design and no changes can be made after the experiment has commenced. This means that a lot of planning is required before the experiment commences (Höst, et al., 2006, p. 36).

2.2.5 Action research

Action research is a closely monitored and documented study of an activity, with the purpose of solving a problem. The steps in action research can be described as; Observe a situation or a phenomenon in order to identify or clarify the problem that is supposed to be solved. For this, a combination of case studies and surveys can be used. The next step is to propose a solution to the problem and solve it. Once that has been made, an important but often neglected part follows; an evaluation and analysis of the solution in order to establish whether it works as predicted. The method closely resembles how quality or process enhancements are carried out (Höst, et al., 2006, pp. 39-41).

2.2.6 Research methods used in this master thesis

The research method that will be used in this thesis is a combination of action research and experimental methods. Since the problem formulation is well defined, action research will be used to identify potential benefits with traceability and propose a solution to the implementation of a traceability system. The experimental part of this thesis will consist of multiple experiments with different types of bar codes, the application of these, and the marking method itself. The process puts unique demands on the marking (i.e. shrinkage/deformation, extreme temperatures and glazing). Therefore, experiments on the specific process are required in order to establish that the marking method actually works as intended.

2.3 Methods for data gathering

2.3.1 Literature review

A literature review is a process in which the researcher critically reviews the literature that is either directly or indirectly related to the field of study. The information that is retrieved gives guidance to the appropriate focus and strategy of the study. By finding out what others know and how they have acquired this knowledge, is helpful in determining whether the research fits into the existing body of knowledge and if it in a unique way contributes to science (DePoy & Gitlin, 1999, p. 82).

2.3.2 Interviews

Interviews are a method for gathering qualitative data, most often performed with a specific individual. The questions in an interview can have different form and structure; it can be segmented in three types of interviewing techniques according to Höst et al. (2006, pp. 34-35):

- Structured interviews – An interview that is based on predefined list of questions and answers that is followed exactly. This roughly corresponds to a verbal questionnaire. The advantage of using a structured interview is that the data collected will be easy to analyze given its limited number of responses.
- Semi-structured interviews – An interview that has a predefined list of question in support of the interview. Nevertheless, the question can change order and sometimes the formulation of the question can be altered considering the situation in the interview.
- Unstructured interviews – Open-ended question is used which lets the interviewee control what is covered in the interview. The control of the interviewee is limited by questions that is supposed to ensure that the interview stay within the area of the study.

2.3.3 Observations

Observation is a technique where the researcher studies a series of situations by using his senses or technical aids and takes note of what happens. The observer can be a participant in the event, or act as a bystander just observing while being invisible to the participants. The advantage of the observer being a participant is that the observer can establish trust from the persons he studies, and the disadvantage is that the researcher risk losing objectivity and distance towards the study. The risk with of being an "invisible" observer is that he risk creating too great of a distance and therefore not admitted into the event properly (Höst, et al., 2006, p. 35).

2.3.4 Experiments

Experiments are carried out in order to find causation and explain why certain phenomena occur. Through experiments, technical solutions can be compared in order to find the most ideal. In an experiment, several parameters that impact on the phenomenon can be studied by vary them and repeat the process. An experiment is of a fix design and cannot be changed after it has commenced. This leads to that an experiment must be well prepared beforehand. The goals with the experiment need to be defined, what should be analyzed? What is the purpose? If two methods is to be compared the starting point is to formulate the null hypothesis i.e. that there is no difference between the methods. This hypothesis is then rejected for another hypothesis if there is a difference between the methods (Höst, et al., 2006, pp. 36-37).

2.3.5 Methods for data gathering in this master thesis

Literature reviews will be a large part of this project since the knowledge beforehand is limited. It will give guidance into what issues that will be focused on and support the creation of a traceability framework for the project.

Interviews will be carried out with both personnel that are vital to the process as well as with personnel that carries out the work at the stations. The interviews will be semi-structured or unstructured depending what is needed for the project from this certain person.

Observations will be carried out in order to achieve an understanding of the production system and the requirements that is put on the traceability system. In order to assure that the observations are correct, interviews with key personnel will be carried out. The production line will be closely observed in order to find out where benefits can be achieved with traceability.

The interviews and the observations is an integral part before the experiments regarding the traceability method commences. This information will make sure that the traceability method can be integrated in the production system. The main focus during the experiments is to make sure that the marking is readable on the material that the products are made of, through all process-steps. Therefore, the pieces will be read after each process-step with different types of reading equipment suitable for that specific marking method. The time to mark the products is also important since there will be time restrictions in the production process. The experiments will be conducted on either samples or products in a laboratory environment. The experiments that are successful will also be conducted in the regular production facilities. This is done to ensure the validity of the experiments.

2.4 Qualitative and quantitative approach

2.4.1 Qualitative

A qualitative method is primary used in order to understand a phenomenon. With different types of collection of data a deeper understanding can be gained. The project group should always be close to the place of data collection (Holme & Solvang, 1997, p. 14). In a qualitative survey the researcher gathers data that is not possible to quantify, i.e. to express it in numbers, and analyzes it with non-numerical analysis methods. The qualitative approach often uses interviews in order to find underlying behaviors (Lekvall & Wahlbin, 2001, p. 210).

2.4.2 Quantitative

In a quantitative study, the collected data can be expressed in a numerical format and analyzed by mathematical and statistical methods (Lekvall & Wahlbin, 2001, p. 210). As opposed to qualitative methods, the quantitative are formalized and structured. The project group controls to a large extent the data collection and it is not necessary for the group to be close to where it is extracted (Holme & Solvang, 1997, p. 14).

2.4.3 Approach used in this master thesis

In order to fully understand the process, a combination of qualitative data and quantitative data will be gathered. With the purpose of understanding the process and to find potential benefits of a traceability system, a qualitative approach will be used. However, in order to validate the qualitative data, a quantitative approach will be used to find cost-benefits with a traceability system.

2.5 Data collection

2.5.1 Primary

Primary data is data that have been collected specifically for the intended study. Usually it is collected through interviews or observations (Björklund & Paulsson, 2003, p. 68). Primary data is collected when conducting field research or laboratory tests (Lekvall & Wahlbin, 2001, p. 212).

2.5.2 Secondary

Secondary data is data that have been collected for another purpose than the one of the project. These data are usually collected through literature studies (Björklund & Paulsson, 2003, p. 67). Secondary data is used when desk research is conducted (Lekvall & Wahlbin, 2001, p. 212).

2.5.3 Data collection in this master thesis

Both primary and secondary data will be used to analyze the problem. Secondary data in this project will consist of data from the ERP system and literature studies. The primary data will consist of data from interviews, time studies and experiments.

2.6 Procedures for analyzing and drawing conclusions

2.6.1 Induction

Induction means that the researcher tries to draw general and theoretical conclusions based on the empirical data that has been collected (Wallén, 1996, p. 47). Researchers who are applying a qualitative approach are mostly using inductive reasoning, i.e. that generalized rules evolves from one specific case or observations of phenomena (DePoy & Gitlin, 1999, p. 17). Inductive reasoning have with the increase of computing power become more useful. With new programming software that searches for correlations in the data, build decision procedures and successively revise its conclusions as the conclusion is compared with new data, theoretical conclusions can be made (In comparison with traditional software that is based on a pre-defined set of rules and procedures) (Wallén, 1996, p. 47).

2.6.2 Deduction

The deductive reasoning assumes accepted, general principles or concepts and then tries to apply these general principles to explain a specific event or phenomenon (DePoy & Gitlin, 1999, p. 17). It can be seen as a top-down approach where the researcher starts with the theory and bases his hypothesis on the theory, which influences on the data collection. Based on whether the hypothesis can be validated or not, the theory is further solidified or might require rephrasing (Bryman, 2002, p. 21).

2.6.3 Abduction

Abduction is a way of drawing conclusion about the cause of an event, by using logical reasoning to figure out what the most common factors are without having the possibility to manipulate them. Abduction reasoning can for instance be used to set a diagnosis of a patient by establishing probable causes, draw conclusions by elimination of different factors, and complement with tests to solidify or discard the diagnosis (Wallén, 1996, p. 48).

2.6.4 Triangulation

With triangulation more than one type of method or data source is used. Triangulation is closely associated with a quantitative research strategy since the reasoning behind it is to use several methods in order to get a greater reliability. However, it can also be qualitative. Interviews can for example assure the project group that they have not misunderstood their observations. Triangulation is generally used to double-check the results in order to make sure that they are reliable. This applies both for qualitative and quantitative data (Bryman, 2002, p. 260).

2.6.5 Grounded theory

In the grounded theory there is a close connection between data collection, analysis and the resulting theory. The aim of the method is to achieve a theory based on the data. The analysis and the data collection should be carried out simultaneously. It is the most frequently used approach to analyze quantitative data (Bryman, 2002, p. 375).

2.6.6 Procedures for analyzing and drawing conclusions in this thesis

The approach to this project will be both deductive and inductive, although carried out in different phases. The deductive approach will be used in order to determine how well the theory coincides with what is identified on site at the factory. The theory will probably not be sufficient for all parts of the project and for the later stages an inductive approach will be used in order to complement the deductive. Theory regarding the specific industry will probably be very limited regarding traceability and thus the inductive approach will be needed.

During the project triangulation will also be used in order to double-check the observations. The system will probably be very complex and interviews with key personnel will make sure no incorrect conclusions are made.

2.7 Thesis value

2.7.1 Validity

The validity of a study is determined by how well the measuring method actually measures what is intended. It is a very hard to determine whether the measuring method is valid or not. In order to validate the method, it would require a different method that gives the correct results (Lekvall & Wahlbin, 2001, p. 304).

2.7.2 Reliability

A high reliability of a measurement is determined by whether it is possible to achieve the same results from multiple measurements, given that the variables are the same every time. If the results vary greatly from measurement to measurement, the reliability is considered to be low (Lekvall & Wahlbin, 2001, p. 306). In order to achieve a high reliability, it is important to be thorough in the data collection and analysis. By documenting every step, it is possible to let other researchers examine the work in order to find weaknesses in the method. For qualitative studies based on interviews, it is important to present the data to the interviewee to confirm that the researcher has interpreted the answers correctly. For quantitative studies, the use of statistical methods, and the correct interpretation of these, is crucial to achieve a high reliability (Höst, et al., 2006, p. 42).

2.7.3 Objectivity

Objectivity is a measure that determines to what extent the author is one of relative neutrality and has reasonable freedom from biases - at the minimum, the author should be explicit about the bias (Miles & Huberman, 1994, p.278 cited by Denscombe, 2007 p.273).

2.7.4 Credibility

Credibility mainly relates to the issue of causality. If there is causality between two phenomena, one of them is called the cause and the other the effect (Bryman & Bell, 2003, p. 34). If the relationship is valid it is credible. Credibility is the strength of qualitative research. Credibility entails ensuring that research is carried out in accordance with good practice (Bryman & Bell, 2003, pp. 288-289).

2.7.5 Transferability

Qualitative research is often of the type of an intensive study on a small group or of individuals that shares certain characteristics. The transferability refers to the degree these findings can be generalized across social settings (Bryman & Bell, 2003, p. 288).

2.7.6 The value of this thesis

The value of this thesis will be evaluated in subchapter *12.1 The value of this thesis.*

3 Frame of Reference

In this chapter research and general information that was available to the authors during the project will be compiled. Traceability will be explained, as well as the design of a traceability system, and available traceability methods. In addition to this the system design of an AIDC-system will be compiled, as well as the implementation of a system, and relevant methods used in the thesis.

3.1 Literature search

A literature search was made to explore the existing scientific literature regarding traceability and the traceability methods. In this thesis, several databases and search terms has been used for the frame of references. Below is a list of databases and search terms.

Databases

Engineering village (Compendex, Inspec), Scopus, ScienceDirect, and Emerald. LUB search provided by Lund University was also used, which includes several of the aforementioned databases and many more.

Search terms

‘Traceability’, ‘Implementation of traceability’, ‘Traceability system’, ‘Production control’, ‘Bar codes’, ‘AIDC’, ‘Direct part marking’, ‘Ink jet’, ‘Laser marking’, ‘Dot peen’, ‘Sanitary ware’, ‘DPM ceramics’, ‘Ceramic ink’

3.2 Concepts of traceability

Kvarnström (2006, p. 21) defined the three concepts of traceability and the relation between them. The part of the frame of reference that is focusing on traceability will be divided into these concepts, see *Figure 1*.

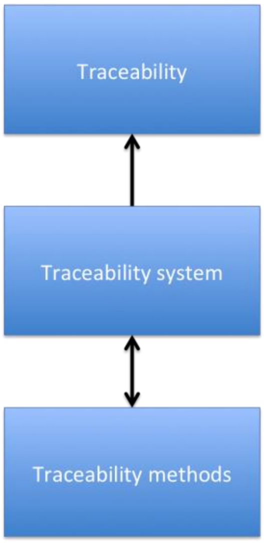

Figure 1 - The three concepts of traceability, adapted from (Kvarnström, 2010)

The traceability system and the traceability methods interact with each other in order to achieve traceability.

3.3 Traceability

3.3.1 Definitions

There are many definitions of traceability and they can be very specific to the highlighted industry. A general definition from the food industry will be used for the project since the research regarding traceability in the ceramics industry is limited. Van der Vorst (2006) defined traceability as "The ability to document and trace a product (lot) forward and backward and its history through the whole or part, of a production chain from harvest through transport, storage, processing, distribution and sales." In order to keep a general approach the word lot is used. The amount of distinct items is not set and can vary from one to multiple.

Since the project carried out in this thesis is closely involved with the quality of the product, another definition highlighting requirements traceability is also added. Robertson & Robertson (2006, p. 353) defined requirements traceability as "A requirement is traceable if it can identify all parts of the product that exist because of the requirement and, for any part of the product you can identify the requirement or requirements that caused it."

The fulfillment of requirements is crucial in order to deliver a quality product. The definition of quality used in this project is retrieved from Bergman and Klefsjö (2007, p. 26) as "The quality of a product is its ability to satisfy and preferably exceed, the customers' requirements and expectations."

The international standard ISO 9001:2008 mentions traceability and the requirements of it in clause 7.5.3. It states that where appropriate the organization shall identify the product by suitable means throughout product realization. It also states that where traceability is a requirement, the organization shall control the unique identification of the product and maintain records (International Organization for Standardization, 2008).

3.3.2 The use of traceability in different industries

There are two industries that are known for the use of extensive traceability, the food industry and the pharmaceutical industry. Both industries are bound by legislative requirements to be able to trace their products to a certain extent (Kvarnström, 2010).

Swedish food producers are for example required to follow article 18 in EG 178/2002. The producers needs to know from whom they have received and/or to whom they have supplied food and food producing animals, and be able to inform the authorities about this. The purpose of traceability is to be able to conduct very specific product recalls. The precision of the traceability is not declared in the article, which leaves it up to the producer to decide the extent in order to reach the purpose (The European Parliament and the Council of the European Union, 2002).

The Swedish Medical Products Agency, i.e. Läkemedelsverket, have stated what needs to be documented by pharmaceutical producers in Sweden in the code of statute 2009:11. The documentation must contain information regarding arrival time and delivery time, number of packages, size of packages, type of pharmaceutical and pharmaceutical form and intensity of the pharmaceutical or an unambiguous product identifier. Alongside this information the supplier and the customer's name and address needs to be stated and it should be clear that the pharmaceutical have been approved, and its batch number. In order to be able to supply this information there needs to be extensive traceability during the whole supply chain of pharmaceuticals, and thus the need of traceability is rather forced by the authorities, in the same way as in the food industry (Läkemedelsverket, 2009).

There are industries that are known to have well-developed traceability systems but where the need of traceability not is directly forced by legislation. One example is the automotive industry, where the vehicles need to be certified for different aspects. The information that needs to be supplied in order to apply for a registration of a vehicle is stated by the Swedish Road Administration i.e. Vägverket, in the code of statute 2007:492. The application must include the type of vehicle, brand and type, model year, chassis number or frame number or equivalent, and the odometer reading. In order for the customer to supply the chassis number the manufacturer needs to equip the vehicle with a marking. These types of certifications are however not the reason why traceability is well developed in this industry, it is the rather the extensive implementation of LEAN production. In order to eliminate waste and continuously improve the operations in accordance with the LEAN principles, traceability is an important tool in order to for example find root causes (Bergman & Klefsjö, 2007).

The marking of products, and thus traceability, are carried out in the ceramics industry as well. If the industry of sanitary ware is highlighted, there are industry-specific labels with bar codes, which are manually applied (Strico AG, 2013). This is the only type of marking that the authors have encountered that is developed with the sanitary ware industry in mind. The markings are readable through the whole production process, and it is possible to attain extensive traceability with this method. There are suppliers that have developed industry-specific IT-systems that take the different processes in consideration. The IT-systems identified by the authors have all been developed with a non-automated production system in mind, which means labor-intensive reading of the products and labor-intensive marking of the products (S.A.I.T. S.R.L., 2009).

3.3.3 The need for traceability

The need for traceability is brought to light when thought to be identical items display differences in characteristics. Töyrylä (1999, p 17-18) identified six factors that can result in differences in otherwise identical items and that eventually highlight the need of traceability.

1. **Age** between different items can be a factor. Depending on when the item is produced there could, for example, be design differences for the same product, alterations in the value-adding processes could also have been made during the products lifetime.
2. **Origin** is also a factor that can cause differences in the items. If there are different sources of the raw material that the items consist of, otherwise identical items can bare different characteristics.
3. **The destination** the item is meant for is another factor that can influence the need for traceability. If there are several locations or markets that the item is meant for traceability is needed in order to, for example, issue a mass recall.
4. **Customization of items** for a special customer order i.e. intentional diversity also results in differences in thought to be, identical items and therefore, highlights the need for traceability.
5. **Errors and variations** within the manufacturing and distribution of the items i.e. unintentional diversity, for the same reasons as for intentional diversity.
6. **The risk for illegal activities** is the last factor and depends on the value of the product. Traceability can be used in order to ensure who were responsible when something was stolen. This factor also includes issues concerning counterfeit products and the identification of these.

3.3.4 The relative importance of traceability

In addition to these factors Töyrylä (1999, pp. 18-20) also compiled five factors for determining the relative importance of traceability. The factors are used in order to determine the appropriate level of traceability.

1. **The value of the item** is a main factor in order to determine the appropriate level of traceability. For example, a high valued item can be entitled to a serial number, and a low valued item to a date code.

2. **The criticality of the item** is another important factor. If the item is critical in relation to the quality or functionality of the item or to the system it is part of, it has an increased need for traceability.
3. **The length of the item's life** also contributes to determining the appropriate level of traceability. The longer item life the higher the amount of items in circulation and thus higher need for detailed traceability.
4. **The complexity of the system** also influences the level of traceability. Examples are, if a replacement of an item is expensive either in monetary values or time, if the item is not protected by a patent or trademark, if a failure in the item affects the system it is related to.
5. **The external environment** can contain a lot of factors. These can, for example be, increased customer concerns with a product and where the raw material is collected. Customers' need of customization of items also affects the appropriate level of traceability as seen subchapter *3.3.3 The need for traceability*.

3.3.5 Benefits with traceability

A well performing traceability system has different areas of benefits. Some of these areas were compiled by Töyrylä (1999, pp. 10-17).

- Product recall
- Product-liability-prevention
- Quality- and process improvement
- Proof of quality and origin
- Logistics
- Security
- After-sales
- Accounting

Product recalls can be issued for a certain product or product batch when considerable errors or variations are identified. There are many costs related to a product recall, such as damage of the reputation for the responsible company, increases in insurance premiums etc. In order to reduce these costs to a minimum a traceability system could be of help in, for example, locating the defect products fast (Töyrylä, 1999, pp. 10-11).

In cases where the product-liability is highlighted, a traceability system can provide information regarding if the company is liable for a defective item or not (Töyrylä, 1999, p. 11). The traceability system can, for example, help to prove that a certain defect of a product was made after it left the responsibility of the manufacturer.

A traceability system will also provide an opportunity for product designers, process developers etc. to gather more information about how the product responds to different changes (Töyrylä, 1999, p. 12).

Proof of quality or origin can be required by end-customers, for example, because of environmental reasons. It may also be required by customers in order to prove that contractual requirements have been met. With a traceability system both can be provided to the customer (Töyrylä, 1999, p. 13).

The opportunities of traceability in logistic applications are obvious. The ability to track a certain product and efficiently plan a distribution route as well as making sure that products are not mixed up during transportation and if they are, simplify the localization of them. Internal logistic aspects also need to be taken into consideration. With a traceability system, changeover times and lead times are clearly visible (Töyrylä, 1999, p. 15).

Security applications can refer to identifying where losses in manufacturing occurred and who were responsible at the time. Other applications can be to identify counterfeit and illegal products (Töyrylä, 1999, p. 16).

The after-sales are also an issue where traceability can be an important aid. Product serial numbers can clearly identify when a certain product was made and therefore verify a warranty claim (Töyrylä, 1999, p. 16). Information on known issues on specific products available for service divisions is another aspect that should not be neglected.

Data from the traceability system can also be used by accounting in order to support them in cost accounting. With traceability, costs can be assigned to where they incur. Another obvious application is to calculate the correct amount of work-in-process and inventory levels. (Töyrylä, 1999, p. 17)

3.3.6 Types of traceability

One must distinguish between different types of traceability, depending on what the traceability is meant for. Jansen-Vullers et al. (2003, pp. 402-404) distinguished between these types.

- **Tracking** is a method of following an object through the supply chain and registering any data considered of any historic or monitoring relevance.
- **Forward traceability** depicts the exploration of where-used relations between objects. These relations depict all end products having consumed a particular raw material of interest.
- **Backward traceability** refers to the exploration of the where-from relations between objects. These relations depict the raw material lots consumed by manufacturing operations for the production of the one particular product and further backward.
- **Active traceability** is a method that considers traceability as a tool to manage quality information through the entire chain and, within a specific link of a chain, for the purpose of process optimization and control.
- **Passive traceability** is a method that provides the visibility to where items are at all times and their disposition.

3.4 Traceability system

According to Moe (1998), a traceability system consists of two different parts, namely the routes of the product and the extent of traceability wanted i.e. what the scope of traceability is. This means that the system should contain all the paths the product can take and where they can be identified, from manufacturing to end-consumer.

3.4.1 Design of a traceability system

Golan et al. (2004) compiled how to design a traceability system considering the scope of traceability.

- **The breadth**, which is related to the amount of information that needs to be recorded by the traceability system.
- **The depth**, which is related to how far back or forward in the chain the system should track data.

- **The precision**, which is related to how precise the system is in pinpointing the products movement or characteristics.

Steele (1995, pp. 53-59) acknowledged four elements that according to him together defined the full scope of lot traceability.

- Physical lot integrity
- Data collection
- Lot-process linking
- Reporting

The physical lot integrity describes how large a lot should be and the integrity of it. The integrity determines the precision of the traceability system. According to Steele (1995) there are three situations that can lead to loss of lot integrity.

- **Lot mismatching**, which means that a lot is transformed into a new lot, but the new lot does not exactly match the source lot.
- **Lot-end mixing**, which means that there has been a failure to keep adjacent lots separated from each other which can result in mixing at the end of one lot and the beginning of the other lot.
- **Lot-sequence mixing**, which means that there has been a failure in maintaining the prioritization principle in the production system when the traceability systems follow that principle.

There are two types of data that needs to be collected by the traceability system. Lot-tracing data that records a lot's movement through different process steps and storage, as well as merging with other lots or transformation into other lots. The second type of data is process data, which records process information that is vital to, for example, quality assurance.

Lot-process linking deals with the linking of the information and the physical lot. The data can either be linked directly with the physical lots identification number or by the date, time and process records. Steele (1995) argues that if the link is made with an identification number it is "tight and accurate". If the second method is used, the lot and process data can be collected independently and linked only when needed. The problem with this method is that retrieval of data can be very time-consuming.

The last element deals with how the data is retrieved from the system. The element is of course dependent on how the information is stored. In addition to this aspects like frequency of access, permitted retrieval time and storage place limitations needs to be addressed.

Golan's and Steele's frameworks do not take the impact of traceability tools in consideration. In order to tighten this gap Reggatieri's product traceability framework (2007, pp. 350-351) is also explained. Product traceability is divided into four elements.

- Lot identification
- Data to trace
- Product routing
- Traceability tools

First of all, lot identification needs to be secured in the traceability system. Relevant physical and mechanical characteristics, as well as, bill of materials etc. need to be available in system. The traceability system also needs to handle data that is collected during the different processes. This element can also include possible confidentiality levels. The data that is handled can also be used to set off alarms when they are not satisfactory. In addition to the lot data and process data the lot routing through the whole supply chain needs to be included in the system in order to trace, for example, which machines or operations the lot have gone through. In order to choose the correct traceability tool different aspects like compatibility with product and processes, degree of automation, data accuracy, reliability, and of course cost.

3.4.2 Integration with an automated production system

The integration of automated traceability in a production system can be carried out by developing a new IT-system, with the purpose of integrating traceability in currently used systems. It is important to investigate if the system that is to be used is capable of handling and routing parts through the various processes. The requirements can be divided into hardware and software requirements. The hardware relates to physical requirements, like what kind of equipment is feasible to use with a certain product as well as how often the products should be read etc. The software requirements take control algorithms, coding techniques, and systems integration into consideration. (Mousavi, et al., 2002)

3.5 Traceability method

Traceability relies on that data can be read and provide information regarding the product. There are many such technologies, but in essence all they do is to facilitate the transferring of information. For example, the transfer of information can be done in plain text or alphanumerical code, optically and electronically readable format and with a variety of other methods. This chapter will focus on technologies that facilitate the transferring of computer readable information, also known as automatic identification and data capture (AIDC), by a variety of technologies.

Furthermore, any type of encoding information on some medium has some conflicting requirements according to Pavlidis, et al. (1990):

- We want the code to have a high density of information.
- We want to be able to read the code reliably.
- We want to minimize the cost of printing (In the case of RFID, the cost of the tag).
- We want to minimize the cost of the reading equipment.

3.5.1 Automatic Identification and Data Capture (AIDC)

3.5.1.1 Bar codes

Bar codes was introduced in the 1970's and have spread from supermarkets to department stores, the factory floor, the military, the health industry and much more (Pavlidis, et al., 1990). One dimensional (1D) bar codes which consist of a black and white stripes, has been the carrier of data to track the movement of items through manufacture and the supply chain, so that businesses may calculate production output, control inventory, forecast revenue and analyze other information. But with the increased demand for more product data, as well as the need to use direct part marking identification (DPMI), for which 1D bar code is inadequate, the two-dimensional matrix code or 2D bar code is the solution (Rooks, 2005). There are variety of techniques for marking the item with the bar codes, normally the symbol is printed into an adhesive label by thermal transfer, inkjet or laser and then attached to the item (GS1, 2010). But in order to create a permanent marking that will last the entire lifetime of a product, direct part marking (DPM) has become more popular in industrial applications. DPM means that the symbol is printed, embossed or engraved directly different materials including metals, plastics, glass and ceramics. The four most commonly used techniques are inkjet, laser etch, dot-peening and electro-chemical etching (Rooks, 2005).

1D Bar codes

One-dimensional, linear type bar codes encode information along one dimension with intervals of alternating colors, usually black and white. The intervals are actually rectangles whose vertical height carries no information but facilitates the scanning process. The bars must have a darker color than the spaces because the scanner sensor relies on the different amount of reflected light from the bars and spaces (Pavlidis, et al., 1990).

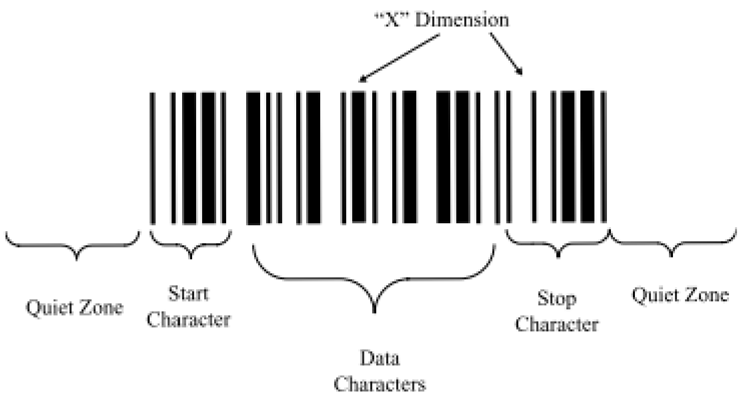

Figure 2 - Structure of a Generic Bar code Symbol (Muller, 2003)

The entire pattern is called the symbol. Each bar and space is called an element, see *Figure 2*. The bar code consists of several "areas". From left to right: the quiet zone, start character, data characters, stop character and another quiet zone. The quiet zones on each sides gives the scanner a starting position from which to starts its measurements. In order for the code the be read from either direction or top to bottom or bottom to top in vertically oriented symbol, start and stop characters tells the scanner where the message begins. The data characters are the actual message or information within the code. These can either be letters, numbers, symbols (+,%,$ etc.), or combination of all three (Muller, 2003). The X dimension is the nominal width dimension of the narrow bars and spaces (Palmer, 2007). For a detailed description of 1D bar code symbologies and how they work, see Appendix 2.

2D Bar codes

2D bar codes consist of black and white modules that are alternatively arranged in the vertical and horizontal direction according to certain rules. It includes a finder pattern, used to identify position, scale, and orientation, see *Figure 3* (Qiang, et al., 2012).

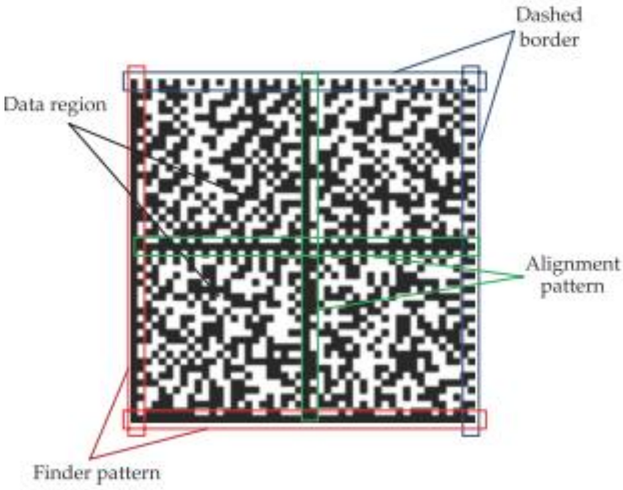

Figure 3 - A four segment Data Matrix code symbol (Qiang, et al., 2012)

There are many types of 2D bar codes, but they all allow for a much greater data density than traditional 1D bar codes. For example, the Data Matrix can hold up to 3116 digits or 2335 alphanumerical characters (Rooks, 2005). Conventional 1D bar codes usually functions as keys to a database, where the code is connected to a database where more information can be stored. The 2D codes, can however store all the relevant information in the matrix which enables off-line access to all the relevant information, such as price, product name, manufacturer, weight, inventory data, and expiration date. This is particularly important at distribution centers that receives from and ships to remote warehouses or overseas depots, in which access to the database is limited (Pavlidis, et al., 1992). Another advantage with the 2D bar codes is that it allows for error correction through a redundancy of information, so that it may be successfully decoded when even as much as 60 per cent of the code is damaged. Since the 2D codes consists of pixels, or dots, and offers error correction, it is suitable for direct part marking (DPM) (Rooks, 2005). Other types of 2D bar codes are PDF 417, QR code and Aztec code. The PDF 417, though classified as a 2D bar code, is in fact a multirow, variable length stacked linear bar code symbol, meaning that the symbol consist of several 1D bar codes stacked on each other (Grover, et al., 2010). For data storage capacity and how the different 2D bar codes look, see Appendix 2.

Even though there are many advantages with the 2D bar codes, questions has been raised that the scanning reliability is much lower than conventional 1D bar codes. Further, the scanning reliability also differs a lot between the different 2D symbologies and also the equipment used to scan them, the material it is printed on and the degree of error correction. It should also be noted that the scanning reliability decreases as the encoded content increases (Grover, et al., 2010).

3.5.1.2 Radio Frequency Identification (RFID)

The RFID technology is an automatic identification system that consists of transponders, readers, and a database. The reader emits an electromagnetic field, and if the transponder is within reach of the reader, a current is induced in the transponder, which in turn sends its stored data to the reader. This is a so-called passive transponder, meaning that it is passive when it is not within the interrogation zone of the reader. A passive transponder does not possess its own power supply but receives its power through an induced current from the reader's magnetic field. Typical ranges of 3 m and a memory capacity of 16 bytes to 8 Kbytes can be achieved with passive transponders. There are also active types of RFID tags. The active tags uses frequencies in the microwave range, which require an internal power, supply in the form of a battery, this powers parts of, or the entire microchip, and enables ranges of 15 meters and above. The memory capacities range from 256 bytes to 64 Kbytes (Finkenzeller, 2003).

The transponder can have different memory capabilities; Read-only, write-once/read-may (WORM) and Read-write transponders. The read-only transponder is encoded with data at the start of the production process and cannot be reprogrammed. WORM transponders can be programmed once, at any given time during the production process. Read-write transponders can be reprogrammed several times during the process, this allows for information to be added throughout the entire production process (GS1 Sweden, 2013).

There are many advantages for RFID compared to traditional bar codes such as no line of sight requirements between the reader and transponder, high data storage capabilities and simultaneous tracking of several items (Finkenzeller, 2003). However, the drawback of RFID is its relative sensitivity to high temperature processes. Even special designed high-temperature RFID transponders can only handle temperature up to 200°C (BALLUF Inc., 2010)

3.5.2 Identification Keys

See Appendix 2.

3.5.3 Bar code reader technologies

A bar code reader is a device that is used to extract the information that is optically encoded in a bar code symbol, and converts it into digital data. We categorize them into input devices and decoders. The input device is usually referred to as scanners, which read the bar code. Whereas the decoder analyzes the signal produced by the input device and deciphers the information encoded in the bar code. The information can be locally stored or sent to a database, which can contain more information that is linked to the bar code (Palmer, 2007).

There are several types of input device technologies, but they all employ electro-optical techniques to scan the bar code. They work by illuminating the symbol with light energy, then examines the amount of light reflected. The symbol's spaces will reflect more light than the bars, providing the decoder with a wavelike pattern, which can be encoded into binary code (Palmer, 2007).

3.5.3.1 Pen-type readers

This type of readers consists of a light emitting source and a photodiode. The pen must be moved at a relatively uniform speed in the horizontal direction of the bar code, thereby registering the amount of reflected light. These readers can either be of contact type or be able to read from a short distance (Palmer, 2007).

3.5.3.2 Laser scanners

Laser scanners work by emitting a laser beam and typically employ a reciprocation mirror or a rotating prism to scan the laser beam back and forth across the bar code. A photodiode is used to measure the intensity of the light reflected back from the bar code. The laser scanner has the advantage that it can be used to scan the bar code from a considerable distance, depending on the power of the laser and to which degree the laser beam is directed back and forth (Palmer, 2007).

3.5.3.3 CCD readers

CCD readers use a linear array of multiple adjacent photo detectors. The array should consist of a sufficient number of photodiodes such that at least two, and preferably four, photodiodes are covered by the narrowest element to be resolved. The CCD type reader can work with just the use of ambient light as opposed to the laser or pen-type scanners that need a light source directed at the bar code (Palmer, 2007).

3.5.3.4 Image-based readers

A image-based reader employs the same methods as the CCD reader. The difference however, is that the CCDs are lined up in a two-dimensional fashion, enabling it to read 2D bar codes. The image readers have the advantage of being able to read partially damaged bar codes, restoring them by software decoding algorithms (Palmer, 2007). The disadvantage of the image reader is that it is a relatively new technology, often causing it to be more expensive than the other technologies (Barcoding Inc., 2013).

3.5.4 Marking methods

There are many methods for marking a bar code onto a material. The bar code can be preprinted on adhesive labels that are applied to the material. It is also possible to mark the bar code directly onto the material - this is known as direct part marking (DPM).

Labels can be printed on with various techniques, and the most common ones are flexography, offset printing, thermal printing, laser and inkjet. The advantages of thermal, laser and inkjet are that it is possible to print very small series or print serialized bar codes (Palmer, 2007). The labels can consist of paper, polyester, and even ceramic materials (Strico AG, 2013).

The marking methods for DPM can be categorized into intrusive and non-intrusive markings. The intrusive marking methods alter the part's surface and are considered to be controlled defects and if not applied properly can degrade the material properties (National Aeronautics and Space Administration, 2008b).

3.5.4.1 Intrusive marking methods

Examples of intrusive marking methods, which can be seen in *Figure 4*, are:

- Abrasive blast
- Direct laser marking
- Dot peen
- Electro-chemical etching
- Engraving/milling

The intrusive marking methods the authors identified as most suitable for marking serialized bar codes in the automated production of sanitary ware are dot peen, direct laser marking and engraving. However, the engraving technique is most suitable for the marking of text and numbers (National Aeronautics and Space Administration, 2008a).Therefore, only dot peen and direct laser marking is covered in this subchapter.

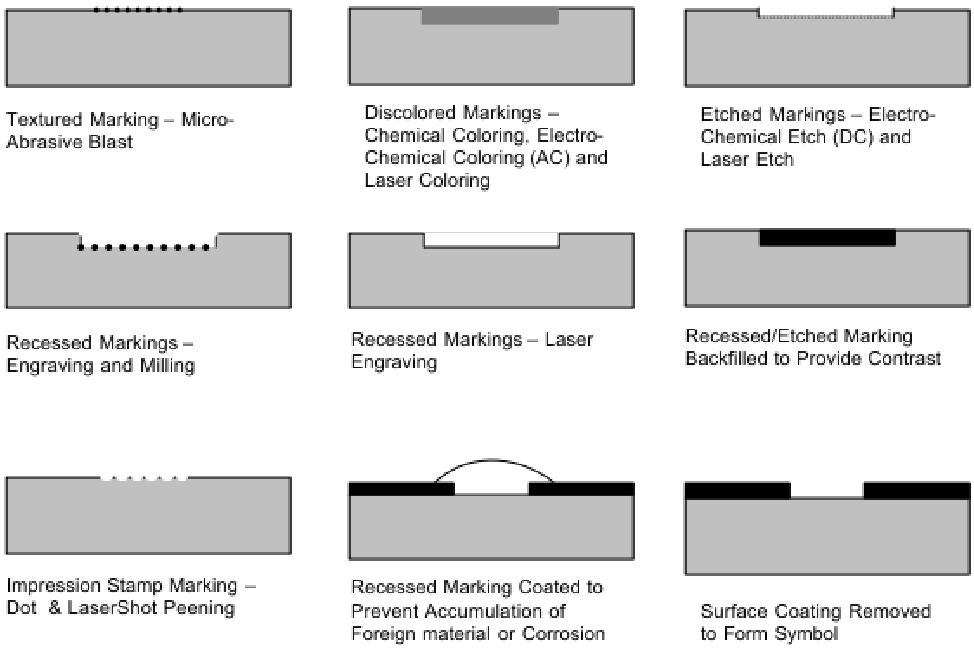

Figure 4 - Examples of Intrusive direct part marking methods (National Aeronautics and Space Administration, 2008b)

Dot peen

The process of dot peening uses a multi-axis stylus point which hits the part leaving a small dimple, see *Figure 5*. It is an impact marking process which is electrically or pneumatically driven depending on the material to be marked. The stylus point is usually made of tungsten carbide or hardened steel, which is forced into the part material creating dimples of up to 1.5 mm in depth and a radius of between 1 and 5 mm. Materials with an Rockwell hardness rating of up to 62 is suitable for dot peening, and the most common material is metals, but it can also be used on plastics and hardwoods (National Aeronautics and Space Administration, 2008a).

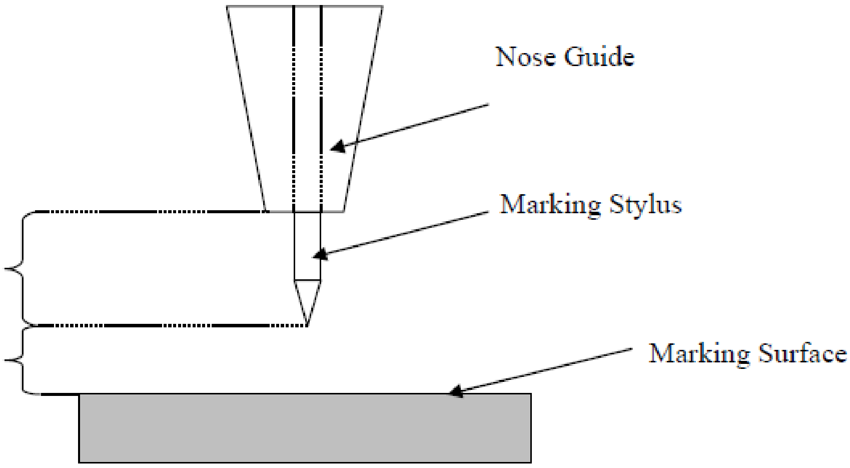

Figure 5 – Structure of the Dot peen marker (National Aeronautics and Space Administration, 2008a)

The advantage of dot peening is that requires no additives, can be stationary or hand held, and is a much cheaper marking method than laser (Elvenger, 2013). However, because dot peening produces a no-contrast mark, successful reading depends on the proper illumination that provides artificial contrast. Projecting light at an angle perpendicular to sidewalls of the dot to reflect light directly to the reader lens creates a data cell that looks brighter than the surroundings to the imager. If the lighting angle is further lowered, shadows cast into the dots to produce data cells that appear black to the imager. This provides limitations to the readability when proper illumination cannot be obtained, as in the case with hand held readers with fixed lighting, see *Figure 6* (National Aeronautics and Space Administration, 2008a).

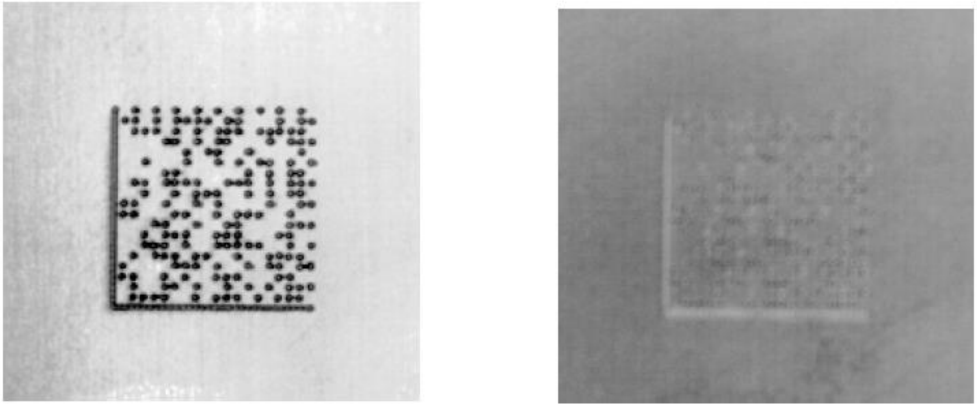

Figure 6 - Dot peen marking with and without proper illumination (National Aeronautics and Space Administration, 2008a)

Direct laser marking

Direct laser marking is an intrusive marking method that includes laser coloring, laser etching, and laser engraving. For laser coloring and laser etching see Appendix 2.

Laser engraving involves even more heat than laser etching and results in the removal of substrate material through vaporization, see *Figure 7*. This technique does not provide the high contrast marking that laser coloring or etching can provide since the discolored material is vaporized. Even though more heat is applied, it generally produces less damage to the substrate than laser etching. However, it can cause micro cracking in some materials and should therefore be carefully evaluated before used on materials in critical applications (National Aeronautics and Space Administration, 2008a)

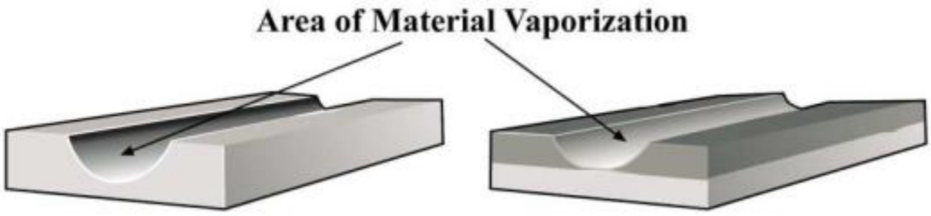

Figure 7 - The left figure displays laser engraving applied directly to the surface. To the right, laser engraving is applied to a surface coating (National Aeronautics and Space Administration, 2008a).

3.5.4.2 Non-intrusive marking methods

Non-intrusive marking methods, also known as additive markings, are produced by adding a layer of media to the surface using methods that does not alter the material properties, see *Figure 8*. These methods include (National Aeronautics and Space Administration, 2008b).

- Markings in the cast, forge, or mold
- Inkjet
- Laser bonding
- Stencil markings
- Thin film deposition

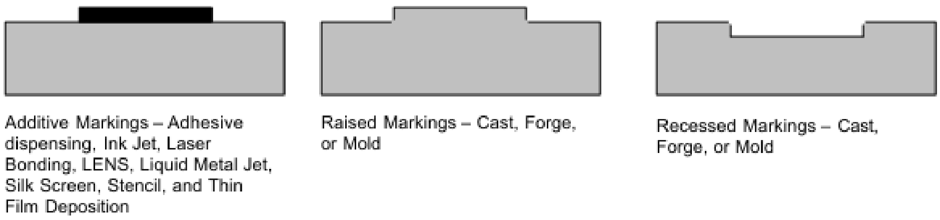

Figure 8 - Examples of Non-Intrusive direct part marking methods (National Aeronautics and Space Administration, 2008b)

This subchapter will only cover inkjet and laser bonding techniques. This is related to the applicability and suitability of the other marking methods for marking serialized bar codes in an automated production of sanitary ware.

Laser Bonding

Laser bonding is an additive, non-intrusive process that involves the bonding of marking materials that generally consist of glass frit powders or metal oxides, nitrates or carbonated mixed with inorganic pigments and a liquid carrier, similar to the materials used to mark porcelain products. These materials can be applied by airbrush, aerosol cans and adhesive tapes. The laser bonding is accomplished using relatively low laser power levels that have no detrimental effect on metal or glass substrates and are therefore safe to use in materials used in critical applications. The bonding is effectively fired onto the surface, causing a permanent mark that is chemically and heat resistant. The excessive bonding material is then removed be alcohol or demineralized water. The advantage of this technique, is that it does not cause any heat affected zone and that it can be used on ceramics, glass, porcelain, metal and plastic substrates using Nd:YAG, Nd:YVO_4, CO_2 or fiber lasers (National Aeronautics and Space Administration, 2008a)

Ink jet

The concept of ink jet is in theory straightforward. A print head propel droplets of ink to the part surface. The ink jet technology is a non-contact, high speed and high resolution printing technique, enabling it to print high resolution bar codes at high speeds (Silversheen Ltd., n.d.).

Ink jet printing can be divided into two types of techniques, continuous ink jet (CIJ) as shown in *Figure 9* or drop-on-demand ink jet (DOD) as shown in *Figure 10*.

CIJ is used for high speed printing in industrial environments. Because of the high ejection speed of the ink droplets, the distance between the print head and the substrate can be in excess of 1 cm. In this technology a high-pressure pump directs ink from a reservoir to the nozzles, creating a continuous stream of ink, which means that the CIJ should be running at all times. The stream of ink is subjected to a vibrating piezoelectric crystal, causing the stream to break up into droplets. The droplets are then subjected to an electrostatic field to impact a charge, the charged droplet passes through a deflection field, creating the desired print on the substrate. Only a small fraction of the droplets are used to print, the majority is not deflected to the substrate but to a gutter for re-use (Silversheen Ltd., n.d.).

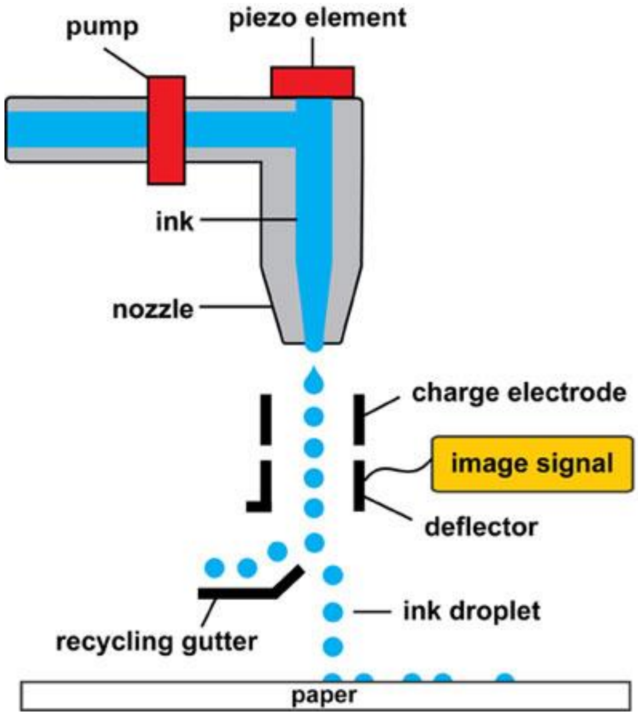

Figure 9 - Overview of the continuous ink jet technology (The DP3 Project, 2012)

The major advantage of this technology is great printing distance, high printing speeds and freedom from nozzle clogging. The CIJ technology has some limitations including relatively low printing resolution, high maintenance and limitations to the inks that can be used because it has to be electrically chargeable (Silversheen Ltd., n.d.).

DOD is a broad classification of ink jet technology where the drops are ejected when needed. The drops are formed by the creating of a pressure pulse. The pressure pulse can be generated by various techniques, which is what defines the sub-classes of technologies within the DOD classification. This includes thermal, piezo, electrostatic, and micro-electro mechanical systems (MEMS) (Silversheen Ltd., n.d.).

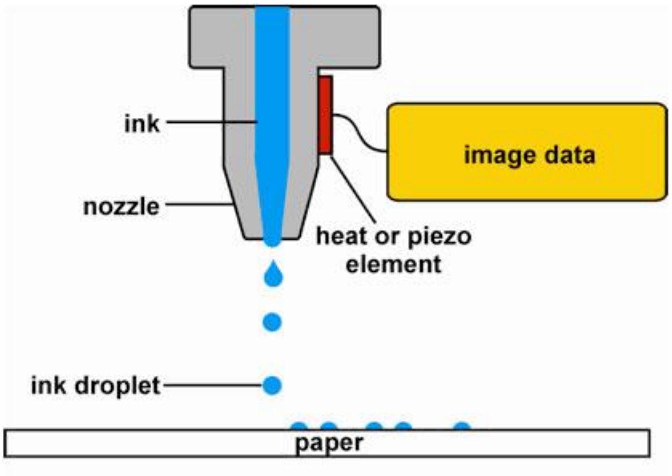

Figure 10 - Overview of the drop-on-demand ink jet technology

The technology most commonly used in industrial applications is the piezo ink jet. In this technology, a piezo crystal undergoes a distortion when an electric current is applied, the distortion is used to mechanically create a pressure pule in the ink chamber thus causing a drop to be ejected from the nozzle. This technology has several advantages such as very high resolutions, long print-head life as well as allowing for a wide variety of inks (Silversheen Ltd., n.d.), including inks with ceramic particles and pigments enabling printing images on ceramic tiles (Xaar jet Ltd., 2010) and even 3-D printing (Zhaoa, et al., 2003).

The limitations of this technology are the low print distance allowed from print head to substrate and the high cost of the print-heads (Silversheen Ltd., n.d.).

3.6 System design

The term system design is used to cover all phases leading up the actual implementation of an AIDC system, which is the backbone of any traceability system. In reality, it is only one of the four phases in an AIDC development project. The four phases in an AIDC project are definition, system analysis, system design, and implementation (Palmer, 2007).

3.6.1 Definition Phase

An appropriate high-level team should be assembled to develop the project's definition. It should include the company's goal with the project, as well as briefly explain the proposed system and compare it to the current system. It should also include a description of the project's budget.

Pearce & Bushnell (2010) lists the following steps in the definition phase:

1. What is the goal of this project, stated in terms of improvement?
2. How do the activities and functions to be improved relate to others in the system?
3. Why were they selected?
4. Compare the improved processes with today's.
5. What types of equipment are necessary?
6. How will the new processes affect the cost of doing business?
7. What are the marketable benefits of this project?
8. Identify the project manager, and explain how his or her normal duties will be performed while the system is being implemented.
9. What problems do you foresee?

During the definition phase, the flow of material and information are also examined and modeled to establish where and why information should be collected (data input) and how that data will be used (data output). When modeling a system, care must be taken to ensure that input data is not overemphasized compared to data output. The system should, presumably, be used to provide useful outputs (reports, summaries, etc.) and not to store data for the sake of it (Palmer, 2007).

Palmer (2007) categorizes the flow of information into three categories:

1. Action information: usually real time data that is used to cause some action, such as directing flow or configuring manufacturing cells.
2. Archival information: this data is not acted on immediately but is stored for traceability requirements.
3. Report information: this data may not be acted on immediately, but is used for decision making, examples would be inventory levels, fault tracing and process improvement, labor hours, or cost summaries.

3.6.2 Analysis and Design Phases

The charts and flow diagrams developed during the definition phase are now used as an important input to the analysis and design phase. These will allow for the decision-making on what information and where it is needed.

This has several implications as to the kind of system architecture that will be used (Palmer, 2007).

3.6.2.1 System architecture

Three types of system architecture can be used: a stand-alone system, a fully integrated on-line system, and a hybrid system. A stand-alone system uses a separate, dedicated computation resource to manage the data collection and storage activities. Data is transferred between the stand-alone system and the company ERP-system at regular intervals in a batch mode.
In a fully integrated, on-line system, all the peripherals, be they printers/markers or readers, are connected directly to the existing ERP-system. A hybrid system provides computing capabilities at the peripheral level, but is still basically a fully integrated, on-line system (Palmer, 2007).

3.6.2.2 Open or closed system

The next step would be to choose whether the system should be open or closed. An open system is designed around widely accepted standards that let them be expanded into many directions. An open system, for example, allows a robotic system from one vendor to share an AIDC database with a robotic system from another vendor. An open system requires the adaptation of both a symbology and an application standard that will allow for many parties to be able to use the symbology and even the database. An example of this is the labeling of food products that will be sold through retail stores where the use of the GS1 system is employed successfully because there is industry-wide agreement on: coding structure, symbology, range of X dimensions, wavelength of scanning, and symbol placement (Palmer, 2007).

A closed system is on the other hand a system where a single user, manufacturer, or institution has total control of the AIDC system, including all printing/marking and reading locations. Because there is no industry-wide requirement for compatibility, the system can have its unique sets of coding structure, symbology, range of X dimension, wavelength of scanning, and symbol placement. There may be a good reason to use a non-standard symbology or marking methods, such as size and marking requirements. But if there are not, sticking to industry-accepted standards is a good idea. This will allow the use of commonly available equipment and the system can easily be converted to an open system at a later time, if desired (Palmer, 2007).

3.6.2.3 Functional specification

Once the system architecture and the decision if it should be an open or closed system have been made, a functional specification should be developed as a baseline for a Request For Proposal (RFP).

The functional specification does not describe the specific software or equipment needs, but rather the function. In this step it is wise to develop the plan internally at the company and not rely on the system vendor, since the personnel has the greatest knowledge of the processes and what will be affected. External help from consultants with experience from these types of systems could be considered in order to not leave any stone unturned. However, these consultants should preferably be independent from any hardware or software vendors (Pearce & Bushnell, 2010).

An outline of the functional specification could be:

- Workflow needs.
- Material handling interface.
- User interface needs.
- Business interface needs.
- Computer interface needs.
- Bar code labeling requirements.
- Bar code equipment considerations.

3.7 Implementation

The system implementation affects the entire production enterprise and even the company as a whole. The magnitude of this effect varies in proportion to the size of the system, but mainly in the changes in operations that are caused by the implementation. Pearce & Bushnell (2010) argues that the major components that will be affected during the implementation phase include:

- Cash flow – preparedness for cash flow imbalances and payments due to disturbance in operations should be accounted for.
- Facility modifications – add or change structure, reconfigure automatic handling equipment such as AGVs and robots, add or change utilities such as power, IT connectivity, add cables etc.

- Human resources – change in job functions and skill levels, training and education must be scheduled
- Operations – change in processes and procedures, changed flow
- Computer and communication systems – upgrade, modify or replace hardware and software

A specific implementation plan with all the topics listed above should be made. It is very important that the implementation is conducted in logical steps, and that the management has put together a project or implementation team with members from all the affected parties. The success of the system relies on that everyone is fully committed and understands why the system is being employed (Palmer, 2007). Therefore, training and education for the personnel is imperative, because change is often met with skepticism and an inability to understand why things have to change (Kotter, 1996, p. 5).

When the system has been operation in the production environment for some months, its capabilities and the success (or lack thereof) should be evaluated. The lessons learn from the initial system can prove valuable in fine tuning follow up AIDC implementations (Palmer, 2007).

3.8 SIPOC

SIPOC is a tool used in order to map the inputs and outputs of a process. It is used to in a fast way get a grip of whom the process receives information from and sends information to, and what kind information. SIPOC is an acronym for Supplier, Input, Process, Output, and Customer. These factors are then compiled in a diagram in order to get a clear overview of what affects the process. The SIPOC can be further extended to include other aspects like what triggers the process to start or crucial points in the process. In its basic design the SIPOC only includes the main factors (Carey & Stroud, 2010). An example of a SIPOC can be found in table 2.

In order to compile a SIPOC, the methods of data gathering, and research methods discussed in chapter *2 Methodology*, can be used.

Table 2 - An example of a SIPOC (Carey & Stroud, 2010)

Suppliers	Inputs	Process (Billing Process Example)	Outputs	Customers
• ? • ? • ?	• Billing Department Staff • Customer Database • Shipping Info • Order Info	Start Step 1 → Step 2 → Step 3 → Step 4 → Step 5 → Step 6 → Step 7 → Start Step 8	• Delivered Invoice	• ? • ? • ?

	Input Metrics	Process Metrics	Output Metrics	
• Staff Expertise • System Up-Time	• System Responsiveness • Accuracy of Order Info • Accuracy of Shipping Info • Accuracy of Database Info	• Rework Percentage at Each Step	• Invoice Accuracy	Quality
	• Time to Receive Order Info • Time to Receive Shipping Info	• Number of Process Steps • Time to Complete Invoice • Time to Deliver Invoice • Delay Time Between Steps	• Invoice Cycle Time	Cycle Time
	• Number of Billing Staff • Invoices Processed/Month and Variability	• Number of Process Steps	• Cost per Invoice	Cost

3.9 Investment analysis

3.9.1 Cost-benefit analysis

Cost-benefit analysis, CBA, is mainly used in order to support social decision-making, i.e. facilitate the more efficient allocation of society's resources. The standard type of CBA, the ex-ante, i.e. where the analysis is carried out before the changes are implemented will be covered in this subchapter.

The CBA can be used both in order to select the best project and to make "go or no-go" decisions regarding a project.

The tool is divided into nine steps that are to be followed:

1. Decide whose benefits and costs counts
2. Select the portfolio of alternative projects
3. Catalogue potential (physical) aspects and select measurement indicators
4. Predict quantitative impacts over life of the project
5. Monetize all impacts

6. Discount for time to find present values
7. Sum: Add up the benefits and costs
8. Perform sensitivity analysis
9. Recommend the alternative with the largest net social benefits

First of all, a decision must be taken regarding who has a standing in the project. If they are affected, their benefits and costs should be counted. All alternative projects needs to be set, this could for example be the changes prompted by the project and the “status quo” of not going through with the project. Aspects that that will be affected with an implementation need to be compiled, and how to measure them determined. In addition to this estimations needs to be made regarding how many that will be affected over the life of the project and beyond. When all the aspects and quantification of them have been compiled, monetary value needs to be attached to all of them. All projects that have either costs or benefits that arise over extended periods of time should take the future costs or benefits in consideration by discounting them. Finally all benefits and costs are added up and sensitivity analyses carried out. Finally a recommendation for the alternative with the largest net social benefits is made (Boardman, et al., 2000).

3.9.2 Net present value

The net present value is the sum of all payments present values. The net present value expresses the value of the investment, with the cost of capital excluded.

$$KV = -G + a\sum_{k=1}^{n}\frac{1}{(1+i)^k} + \frac{S}{(1+i)^n} \qquad (1)$$

KV = Net present value

G = Initial investment

a = Annual cash surplus

n = Economic life

i = Cost of capital

S = Salvage value

A = Equivalent annual cost

An investment is profitable if the net present value is equal to or exceeds 0. When different alternatives are compared, the alternative with the largest net present value is the best alternative (Persson & Nilsson, 1999).

3.9.3 Equivalent annual cost

With the equivalent annual cost method, the cost per year of owning, operating, and maintaining an asset over its entire lifespan is calculated. The annual surplus is an average during the economic life.

If the annual cash surplus is identical every year the equivalent annual cost is calculated according to:

$$A = \left(\frac{S}{(1+i)^n} - G\right)\frac{i}{1-(1+i)^{-n}} + a \qquad (2)$$

If the annual cash surplus differs from year to year the annual cost can be calculated according to:

$$A = KV\left(\frac{i}{1-(1+i)^{-n}}\right) \qquad (3)$$

An investment is profitable if the difference between the average cash inflows surpluses and the yearly cost of capital is positive. When several alternatives are compared the alternative that attains the largest positive difference is the best alternative (Persson & Nilsson, 1999).

3.9.4 Payback-method

With the payback method, the time to regain the invested capital is calculated. In its simplest form the interest rate is neglected. The initial investment cost is divided with the annual cash savings, and a payback-time in years is attained

$$PB = \frac{G}{a} \qquad (4)$$

The calculated payback-time is then compared to the payback-time set by the company, and if less the investment is profitable. If several alternatives are available the alternative with the shortest payback-time is the most profitable (Persson & Nilsson, 1999).

4 Empirics

A comprehensive description of the current situation is carried out in order to make good judgments for the traceability system and the marking method. This chapter deals with the general flow of goods through the factory, the flow through a specific line, the claim information's way from the end-customer to the factory floor as well as information flows relevant to an implementation of a traceability system.

4.1 Requirements of traceability at Ifö in Bromölla

The factory in Bromölla is ISO9001:2008-certified and in order to be that they must be able to, where appropriate, identify the product by suitable means throughout product realization. How much traceability that is required is up to the customer. Products that are delivered to the large private brand customers are handled in a specific way on order to satisfy their need for traceability. How it is conducted can be found in subchapter *4.2.13 The special handling of products for the large private brand customer*.

4.2 Description of the production system and the claim situation

The information compiled in this sub chapter have been gathered by observations of the different parts of the production system, in addition to this, interviews with key personnel at these parts of the production system have been carried out in order to validate the information attained by observations. Information regarding the claims has been attained from interviews with key personnel at the service unit and the quality control.

4.2.1 Description of the products produced at Ifö in Bromölla

The main products that are produced in Bromölla are water closets, washbasins, and vanity tops. The production of all products is basically conducted in the same way. The main raw material is clay, which passes through different process-steps in order to achieve the end product's wanted properties. The clay is prepared by the slip preparation, that adds other materials to the clay, and it is thus called slip after the preparation.

There are two types of slips that are casted in order to attain the wanted shape of a piece. These two slips are vitreous china, VC, and fine fireclay, FFC. For the sake of simplicity VC can be explained as a fine grained and vitreous slip. Pieces that are made out of VC becomes completely vitreous when glazed which means that it has a porosity of less than 0.5 %, and makes it ideal for environments with high risk of exposure to water. There are however disadvantages as well with the advanced vitrification, it causes shrinkage and a higher risk for plastic deformation. This leads to limitations in what shapes and sizes that can be casted with the VC-slip, if wide washbasins are casted with a VC-slip there is a high risk that the piece obtains an unwanted form after firing. The second slip used, FFC, is basically a VC-slip has been altered in order to reduce the vitreousity. The reduction of vitreousity leads to less shrinkage, both in the dryers and in the kilns. The porosity is however increased as well, which makes the piece more vulnerable to exposure of moist and water. This means that it is vital for FFC-pieces to be completely coated with glaze in locations where moist or water can be a factor. The coating of glaze is important for the VC-pieces as well but not as vital as for the FFC-pieces due to its lower porosity. Another factor that differs depending on the slip is the strength of the material. A VC-piece can withstand more force than an otherwise identical FFC-piece due to the fact that the FFC-piece is more porous. The composition used by Ifö for the FFC-pieces have a substantial difference in the firing shrinkage in comparison to the VC-pieces. The total shrinkage for a VC-piece is 12 % to compare against the FFC-piece that shrinks 3.2 %. The porosity is however less than 0.5 % for a VC-piece and 17.4 % for a FFC-piece. It is also worth to mention that the FFC-slip is a more refined product, and thus more expensive.

A water closet normally consists of two parts, the cistern and the bowl. These two pieces goes through the same process-steps with the only difference that the cistern is water-cut in order to attain the bottom hole that supplies the bowl with water. The two pieces are then assembled, equipped with non-ceramic parts and packed, either manually by an operator or automatically in a robot cell. There is however water closets where the bowl is connected to an external, often wall mounted, cistern. Due to its low porosity, the VC-slip is used for the bowls and the cisterns and thus the contact with moist and water becomes less critical. The fact that the VC-slip products are stronger than products made from FFC is also an important factor for these products.

The washbasins and the vanity tops only consist of one piece. A vanity top is a washbasin that is placed on another piece of furniture. For the standard washbasins the VC-slip is used due to its low porosity and the rather simple shapes that are formed. For vanity tops and the more complex washbasins

FFC-slip is used since straight wide shapes are very vulnerable to plastic deformations. The risk of forming of these unwanted shapes is minimized with the use of the FFC-slip.

4.2.2 The general flow of goods

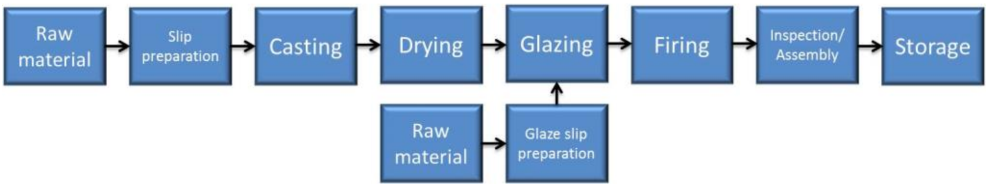

Figure 11 - General flow of goods through the factory

The main material in the products, clay, is transported from Great Britain where it is extracted. On site at Ifö the clay is mixed with, among others feldspar and kaolin, in order to obtain the desired properties. The slip is prepared by the slip preparation and is then transported to an arbitrary production line where the slip fills the mold and is high pressure casted. During the casting phase the slip is formed to its desired form. After the desired form is obtained it is transported to a dryer. The drying phase is needed in order to remove undesired water for the forthcoming phases. The piece is then glazed in order to add color and improve the surface characteristics of the piece. After glazing the piece is fired in a kiln in order to achieve its final structure and properties. It is then inspected in order to identify unwanted properties. If accepted, it is sorted, packed, and transported into a buffer stock or it is sent to an assembly line. If it is not accepted it is either re-fired for a maximum of three times or discarded depending on the fault. The general flow is illustrated in *Figure 11*.

A re-fired piece is a piece that has been declined by the inspection. If the piece possesses major flaws that cannot be fixed with some minor repair it has to be managed by an operator and then fired in a kiln again. The re-firing of a piece is not economical after the third time it has been re-fired.

4.2.3 General overview of the production lines

The factory can be divided into the FFC-slip lines and the VC-slip lines.

Vitreous China-lines

- Standard washbasin
- Bowl and cistern

Fine fireclay-lines

- High volume
- Mid-range casting

The standard washbasins line is thoroughly explained in the subchapter *4.2.4 The production line for standard washbasins.* All other production lines are basically designed in the same way. Each casting cell and glazing cell is thus equipped with an industrial robot. Short descriptions of the other lines can be found in Appendix 3.

4.2.4 The production line for standard washbasins

All the production lines in the factory follows the general four phases, i.e. casting, drying, glazing and firing, and in order to quickly get an understanding of the production system, the focus was directed at the production line for standard wash basins. The reasoning behind this choice was that the flows are evident in this line, and thus easy to follow. Another reason is that it due to its good performance most likely would serve as a pilot for the traceability system. An example of the products that are produced in this production line can be found in *Figure 12*.

Figure 12 - Ifö Sign washbasin 7322

The mapping of the production line was carried out through interviews with key personnel and observations. This information was used to construct a SIPOC chart and a process flow map. The process flow map can be found in *Figure 13*.

The goal with the SIPOC chart and process flow map is to attain a greater understanding of the production line, and with this knowledge support identification of for example, suitable marking points or control points.

The reasoning behind choosing casting, as the first process phase is that it is during this phase the piece is created, and in which it can be marked. The process ends with the inspection and the reasoning behind this is that it usually is the last point where a defect is identified before it leaves the factory.

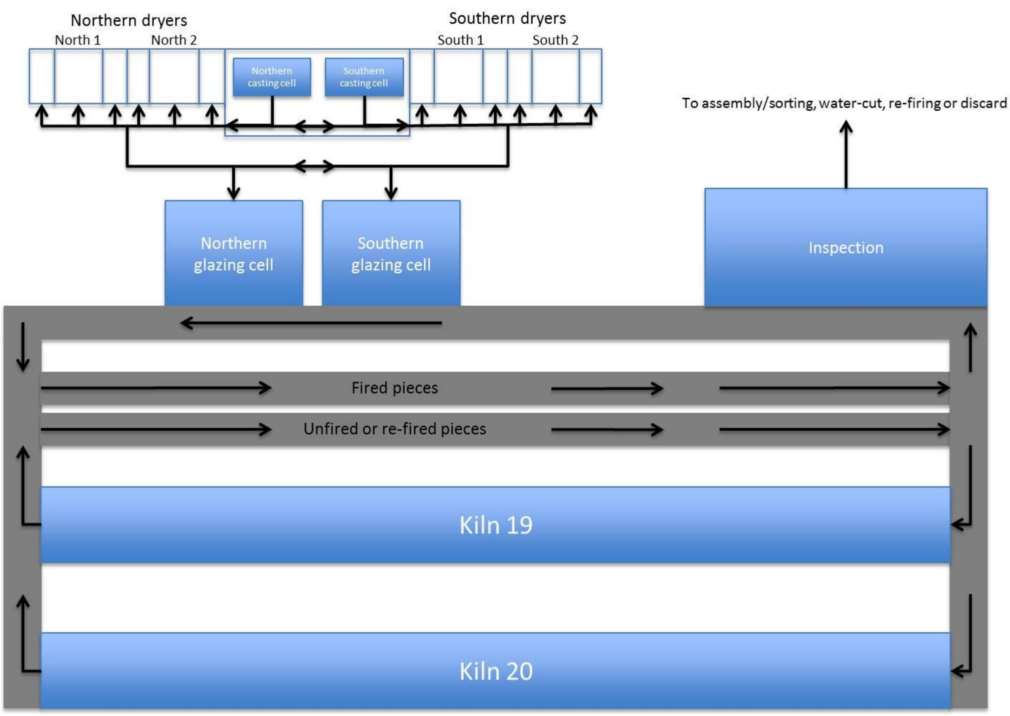

Figure 13 - Flow map for the standard washbasin production line

The production line is highly automated with casting batteries and robots that carries out most of the value-adding steps. The line consists of two casting cells, the northern and the southern cell that dictate what glazing cell the piece will take. The pieces can however be placed both in the northern dryers and in the southern dryers.

4.2.4.1 Casting

The casting phase commences with the mold being filled with slip that has been prepared for casting by the slip preparation. The order for what is to be made and when, is supplied by a production scheduler that has estimated what needs to be produced, with the help of sales forecasts received from the marketing department. There are two casting cells in this production line, the northern can cast 12 pieces simultaneously and the southern 11 pieces. The slip is high pressure casted in batteries for approximately 20 minutes. When finished all molds are opened and emptied by an industrial robot, see *Figure 14*.

Figure 14 - An industrial robot demolds the piece in the casting cell, with green demolding plates in front

The mold is then filled again and a new cycle commences. The emptying of the molds phase takes approximately 5 minutes. During the casting time the industrial robot places the pieces on demolding plates where additional finishing work is carried out by the robot. This work takes approximately 17-18 minutes for all pieces and the pieces is then moved to a rack by the robot, the robot is then idle for a couple of minutes before a new cycle commences. The rack stands at its position until it is filled and a dryer is unoccupied. An operator then manually transports the rack with a forklift into the dryer.

4.2.4.2 Drying

There are a total of four dryers, see *Figure 15*, connected to the line, the dryers consists of three drying rooms each. The time to fill a dryer is approximately 6 hours. The pieces are dried for 16 hours and 45 minutes in order to remove water from the pieces. If not done properly the piece will lose its wanted shape, or even worse, explode during firing. A dryer can fit 24 racks, which is approximately 360 pieces.

Figure 15 - South 1 dryer, with pieces on racks inside and the production line forklift in front

4.2.4.3 Glazing

When the piece have been dried, the racks is retrieved by an operator with a forklift and transported to the glazing cell, where three racks can stand in line to be used by the industrial robot that carries out the glazing phase. The robot picks the piece from the rack and places it on a glazing plate where it can be rotated in order for the robot to glaze it, see *Figure 16*. Only one piece can be glazed at one time in each cell. Depending on what brand or product that is to be glazed the time differs between 2-3 minutes per piece. When the piece has been glazed it is placed on a kiln car that automatically transports the pieces to the kiln. The transport time from the glazing cell to the kiln is approximately three hours. During this time, an operator manually marks the piece with a logo.

Figure 16 - The southern glazing cell, with a kiln car in front

4.2.4.4 Firing

The pieces can either be transported to tunnel kiln 19, see *Figure 17,* or tunnel kiln 20 where the kiln car moves through the kiln for 12 – 16 hours, reaching a top temperature of approximately 1205° C. The temperature is however much lower underneath, and on the sides of, the kiln car. The lower part of the kiln car only reaches a maximum temperature of 250° C.

Figure 17 - Tunnel kiln 19, with bowls on a kiln car in front

4.2.4.5 Inspection

When the piece has been fired it is transported to the inspection where a final evaluation is conducted. Every time a new piece reaches the inspection station, see *Figure 18*, the inspector examines the piece and enters the part number, kiln, glazing cell, mold number and if the piece is approved, need re-firing or if it is discarded. If the piece needs re-firing or if it is discarded, the defect and the location of it are also entered. However, it is only the most severe defect that is reported so even if the piece has multiple defects, only one is reported. Three defects can be supplied to the ERP-system, but only one is supplied since it takes a lot of time to type in every defect into the system. After the inspection the inspector sorts and packs the piece, places it on a pallet and moves the pallet to a zone where an AGV can retrieve it. Re-fired pieces are placed on separate pallets and are then also placed in the AGV zone, these pieces are however not packed. In the AGV zone, a label containing a bar code with a location code is printed out and placed on the side of the side of the pallet. This bar code is scanned during the AGV's route and gives the AGV a drive-to-destination. The discarded pieces are placed in an open container.

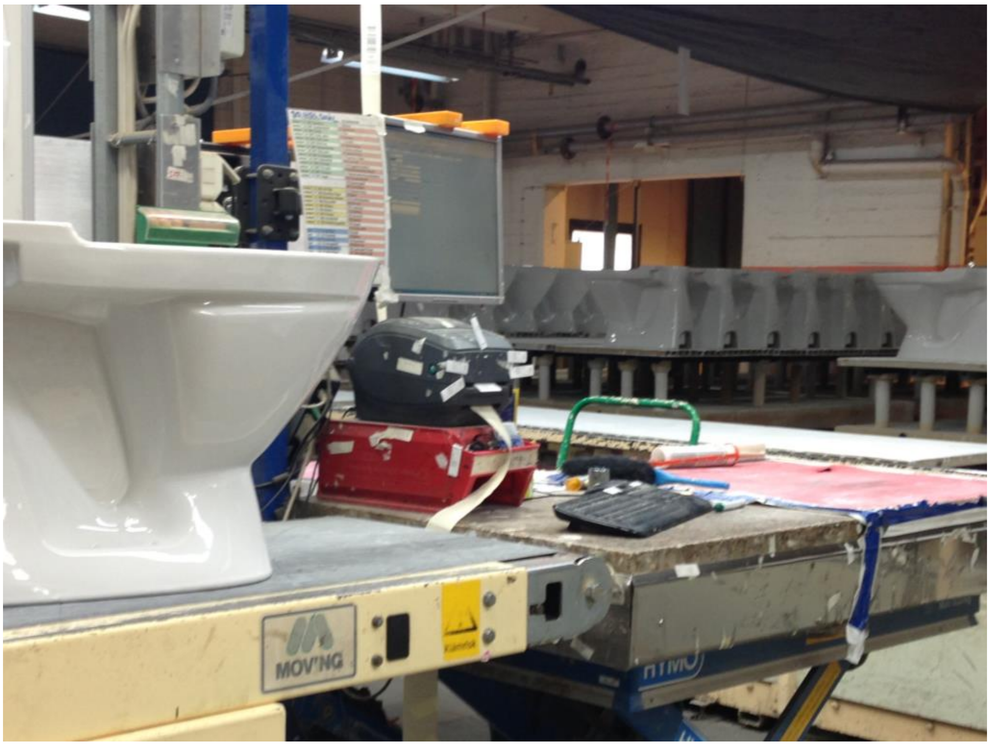

Figure 18 - Inspection station for VC-pieces

4.2.4.6 SIPOC

Table 3 - SIPOC table including Critical to Quality

SIPOC Standard Washbasin Production line				
Suppliers	Inputs	Process	Outputs	Customers
• Mold stock • Slip preparation • Glaze slip preparation • Production schedulers • Inspection • Quality Control	• Mold • Slip batch • Glaze slip batch • Production order • Defect information • Claim information	Casting ↓ Drying ↓ Glazing ↓ Firing ↓ Inspection	• Physical piece • Amount of pieces • Amount of scrap • Mold • Inspection report	• ERP-system • Quality Control • Assembly • Warehouse
	Critical to quality Inputs	Critical to quality Process	Critical to quality Outputs	
	• Density • Viscosity • Specific surface area	• Philistines • Skew • Crane hole dimension • Overflow hole dimension • Carrier placement	• Inspection parameters	

During the casting phase the mold stock, the slip preparation and the production schedulers supply the process. The production schedulers supplies the process with what, when and how much should be produced. The slip preparation supplies the molds with the slip needed to produce the piece. The mold stock supplies the process with new molds depending on what is ordered from the process. During the glazing phase the process is supplied by the glaze slip preparation with the glaze needed to protect the piece. The whole process is also fed with information regarding defects from the quality control. Information regarding defects, is also supplied directly from the inspection to the affected process cell, see *Table 3*.

The customers of the process are the ERP-system, the quality control, the warehouse, and the assembly. The warehouse is supplied with pieces from the inspection phase. These are transported with AGVs from the process into a buffer stock. The ERP-system is updated daily with number of casted pieces, number of glazed pieces, and discarded pieces. The number of casted and glazed pieces is typed into the system by the operators at the production lines, manually, and the discarded pieces are forwarded to the production supervisor vocally. The enterprise system is also continuously updated with inspection reports from the inspection phase. Quality control is supplied with both the pieces to do product revisions and information on actions taken to avoid defects.

4.2.5 Non-conformance handling in general before the piece leaves the factory

Most defects are identified in the inspection where the piece is marked as re-fired or discarded. There are however some cases with small defects that can be handled without the need for the piece to be re-fired. These are marked as approved and sent to a station that handles minor defects. During the continuous inspection information is vocally passed over to the process support at the production line. The defects are registered in the ERP-system, but the changes made to the processes as a result of information from these defects are never registered in any system.

In addition to the continuous inspection, product audits are occasionally carried out by quality control after the product has been inspected. If the pieces are located in the finished goods warehouse, samples can be retrieved and sent back to quality control for random audits.

If a pallet is placed in a storage location at a certain time, there is no way to identify a specific location of a piece. The precision is poor, the only information that can be retrieved is a pallet location, which can hold up to 20 pallets.

There are three different storage locations with different purposes and size. The high volume storage racks can hold a maximum of 20 pallets and these racks are reserved for one product. The low volume storage racks can hold 4 pallets of the same product. There are also storage locations, on the floor, that are reserved for a small number of pallets with a multitude of different products. The high volume racks are LIFO based, which means that the pallet placed first in the rack is very hard to retrieve, making tracing specific pallets in these racks extremely cumbersome.

4.2.6 General flow from inspection to distribution

Depending on what type of product the piece is it goes through different paths, see *Figure 19*. A washbasin is assembled and packed. Once the washbasins has left the inspection it is fetched by an AGV and transported to another hall where it is wrapped in plastic and placed in a buffer stock. There are product codes on each and every piece's packaging. There should also be a label on each piece with information of who inspected the piece and when.

Bowls are placed on a pallet by the inspector and transported by an AGV to the assembly where it is stored until it is assembled with the cistern and other non-ceramic parts. Inspection reports are not filed for the cisterns. They are only inspected, placed on pallets by the inspector and manually transported to one of the two water cut-cells. After the cisterns have been water cut it is placed on a new pallet and transported by an AGV to the assembly where it is inspected, and stored until it is assembled. The bowl and the cistern is assembled and packed either automatically by a robot or manually by an operator. There are 6 automatic assembly cells and 2 manual assembly cells. Each piece's package has a label that contains the part number. For those water closets that are assembled manually, a label with the part number is also placed visible on the plastic wrapping. The water closets are then placed in a buffer stock.

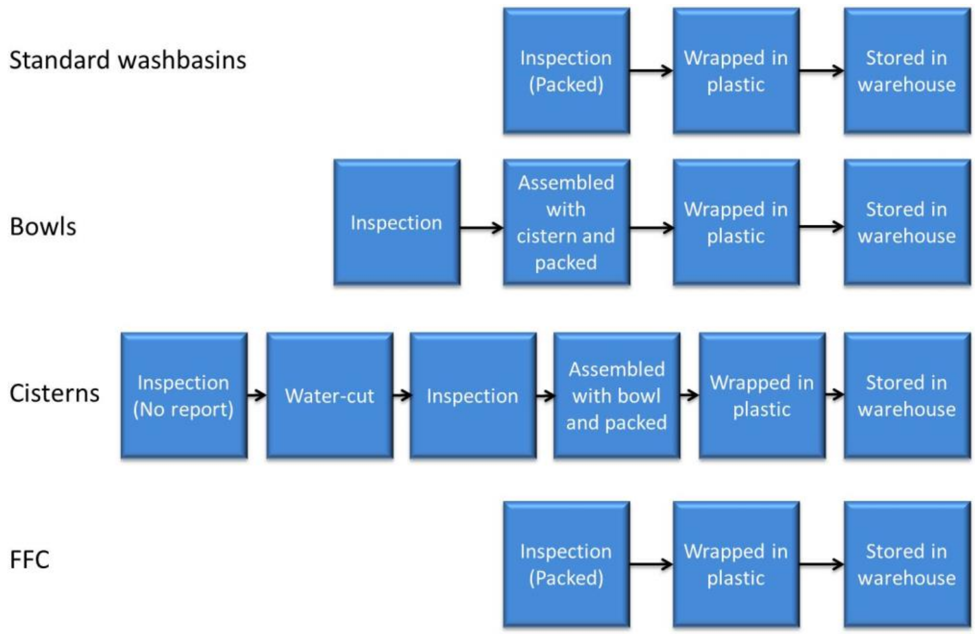

Figure 19 - Flow of goods for the different production lines from inspection to storage

Re-fired pieces are transported by the AGV's to specific re-fire zones, where re-firing personnel fetches them and stores them until they are to be repaired and re-fired. The pieces are either re-fired in the shuttle kilns, which are dedicated to re-fired pieces, or the tunnel kilns where non-fired pieces are fired. A single operator inventories the re-firing stock once a week.

The forklift operator retrieves pallets from three pickup zones depending on where the piece has been produced. The operator always retrieves two pallets at the time and a pallet normally consists of only one type of product, the part number is manually retrieved with a scanner from the bar code sticker. The operator then types in the number of pieces into the ERP-system, which assign the pieces to a storage location.

The pallets are then placed in that location and stays there until they are either distributed pallet wise, or moved to a pick area where they are unwrapped in order to easily distribute smaller amounts of items. When shipped, the order number can be used to trace the amount and product number. Each relocation in the warehouse is typed into the ERP-system, there are however no more information given than the part number and the amount.

4.2.7 General claim information flow for the Ifö brand

As soon as the finished product leaves the finished goods warehouse, it is the service unit that is responsible for claims associated with the product.

When a product leaves the factory it is to the most often transferred to a wholesaler. The wholesalers distribute the product to department stores and plumbing companies. Ifö gives a two-year warranty on every product to their customers, usually to the wholesaler.

When a customer reports a claim to the service unit, a new case is opened in the customer relationship management system, CRM. This case is added with information vital to the claim. If the claim is accepted, the service unit sends out a service technician to the customer that either replaces the product or repairs it. When the service technician is finished with the claim, he proceeds to file information regarding the claim into the CRM-system. Statistics from this system does not reach the service unit or the quality control unit since the CRM-system is not compatible with the ERP-system. There are however ongoing discussions regarding the compatibility between these systems.

The information that the service unit and the quality control unit have access to is only the orders for replacement units that the service technician does, see *Figure 20*. To place a replacement order, a cause of failure is required, which might or might not be known to the technician at that time.

The information is based on what the technician believes to be the cause of failure before he actually sees the product. Also, a lot of information regarding the cause of failure is missing since the service technician may have a stock of replacement parts for which no ordering information has been given.

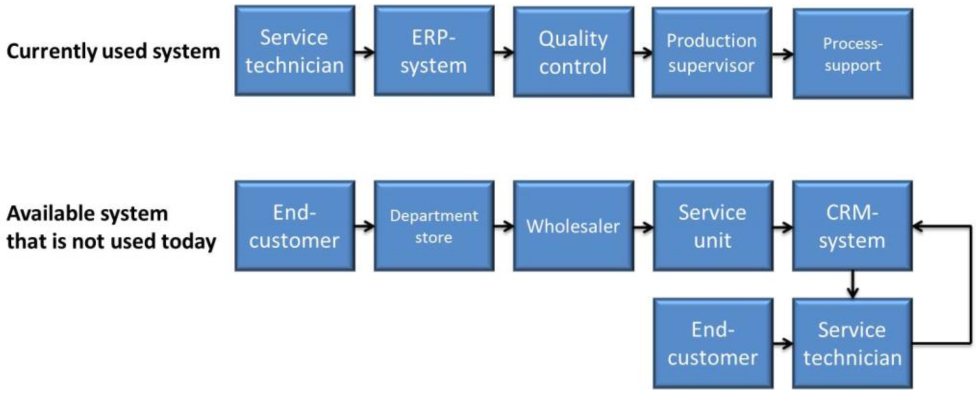

Figure 20 - The two claim flows for Ifö's claims handling

The information that the service unit and quality control have access to is fetched from the ERP-system. Quality control is continuously fed with this information.

4.2.8 Claim flow within the factory

Ifö is part of the Sanitec group, which means that all of the 14 brands in the group can be manufactured to some extent in the factory. Except for these brands they also manufacture products for private brands. The claim flow differs depending on which brand that is highlighted. Ifö manufactures for, and receives claims for these brands:

- Allia
- Colombo
- Ido
- Keramag
- Kolo
- Koralle
- Porsgrund
- Pozzi
- Selles

- Sphinx
- Twyford
- Varicor
- Private brands

Claims regarding the brands Ifö, Ido, and Porsgrund are continuously retrieved from the ERP-system by the quality control. The quality control in Bromölla also has access to the system where claims regarding Sphinx are recorded. The private brands supply the quality control with claim information in very different ways, some brands stock the pieces that have been involved in a claim and personally go through them with personnel at Ifö in certain time intervals, other compiles SQR-reports for single failures and cost of poor quality-reports every month. Monthly reports on claims are also received from the other brands in the Sanitec group.

The information is compiled by quality control and is distributed vocally to the responsible production supervisor once a month. If the information is considered to be relevant and current, the supervisor informs the process-support. The production line then responds to quality control if the non-conformance has been resolved before or is still an issue. The quality control also supplies the production lines with claim information electronically. A figure acknowledging the chain of command in the production lines can be found in Appendix 3.

4.2.9 Information flow relevant to a traceability system

During the production process the central hub for information is the ERP-system. The operators record number of casted pieces as well as number of glazed pieces, of each product, manually every day, and in some production lines every shift. This information is either submitted directly into the ERP-system, or to a production supervisor who submits the information into the ERP-system. It is only the bowl and cistern production line that carries out the latter. An overview can be found in Figure 21.

The process is supplied with information regarding defects, mostly from inspection but occasionally also from the quality control. The production scheduler supplies the process-support with information regarding what needs to be produced in and in what volumes. Information is retrieved from the industrial robots and is supplied manually to an OEE-system that compiles reports for each robot. All kind of process changes and parameters are kept at the production line and these are not transferred to any other system.

An operator monitors the three tunnel kilns continuously and every three hours the temperatures in different parts of the kiln is registered as well as oxygen levels and the kiln cars' sliding speeds through the kiln. For two of the kilns this work is carried out automatically, however, for the oldest kiln, tunnel kiln 19, this has to be carried out manually by the operator.

When the piece has been inspected, the inspector supplies the ERP-system with a report for each piece. From the ERP-system, each production supervisor can retrieve information, for example, regarding number of casted pieces for a certain product last week.

When an order for a certain product is sent into the ERP-system, all components are ordered back through the process. This includes the estimated amount of slip and glaze slip needed. If a piece is mishandled, or if it is has defects that are irrecoverable before it goes into the kiln, the operator should personally inform the production supervisor of this loss in volume so that the supervisor can make corrective changes into the ERP-system.

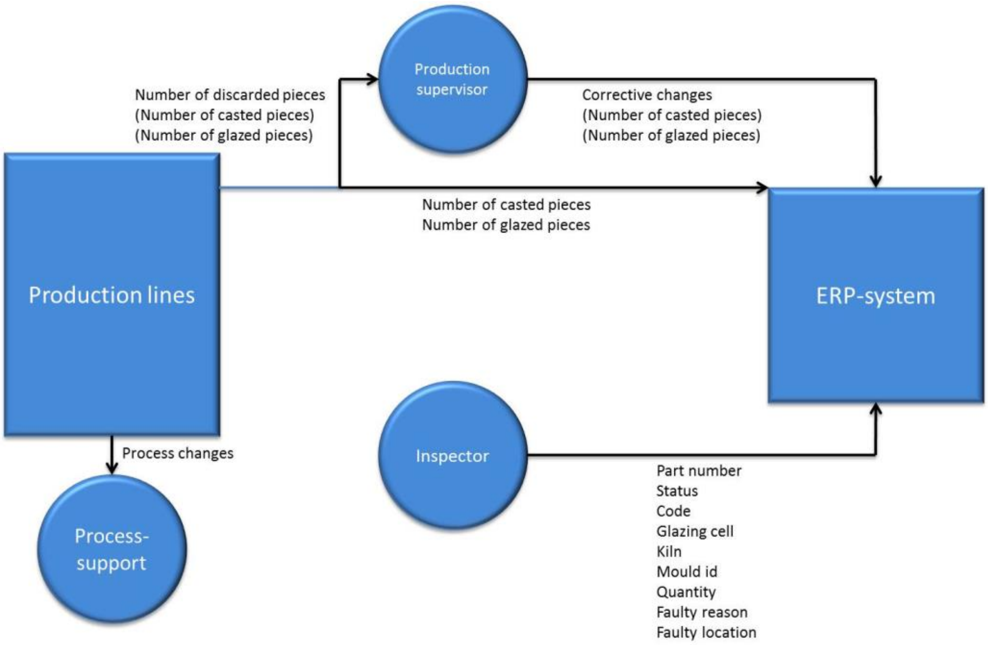

Figure 21 - The information that is supplied to the ERP-system from the production lines

4.2.10 How the ERP-system handles the information from the production lines

Each process-step mentioned in the subchapter *4.2.4.6 SIPOC* is divided into different operations in the ERP-system, there are however several other operations available in the system. Only three process-steps mentioned earlier, the casting cells, the glazing cells, and the inspection, send manually obtained information daily into the ERP-system.

Each casting cell in the factory is fed with a certain amount of clay that is reported by slip preparation into the ERP-system. In order to not accept too large discrepancies, there needs to be a sufficient amount of slip declared before the number of casted pieces can be reported into the ERP-system. When the number of glazed or soon-to-be glazed pieces is reported into the ERP-system, there needs to be a sufficient amount declared from the previous casting cell for the sake of not causing stock imbalances. The glaze preparation also needs to submit amount of glaze that has been provided to the glazing cell.

When the piece reaches the inspection it can be declared as either accepted, in need of re-fire or discarded. If accepted or discarded the number of glazed pieces in the glazing cell is deducted from the glazing operation as well as the amount of glaze. If there is not a sufficient amount of the specific product type available at the glaze operation or not a sufficient amount of glaze declared for that cell the inspection report for the piece cannot be received by the ERP-system. As soon as the piece has been accepted, it is transferred to a buffer stock in the ERP-system until the warehouse personnel fetch it and transfer it to the finished goods inventory.

4.2.11 Corrective changes into the ERP-system

The production supervisors and the production schedulers can make corrective changes to the stock values when errors are discovered. They can either reverse the piece, meaning that the piece is removed from that certain operation or stock and the material that was used to make the piece is transferred back to the latest operation. The piece or number of pieces can also be discarded which means that it is registered as a loss, the material is also registered as a loss.

4.2.12 Current traceability

In order to explain the current traceability in a satisfying way, this subchapter needs to be divided into what process-step that needs to be traced, and which line the piece comes from. Each production line has different conditions and possibilities. There are no information regarding when a certain piece have gone through a certain process-step available at any time. Estimations regarding when a piece has gone through a certain process-step can, however, be made by backtracking the piece. This becomes cumbersome after the inspection, especially if the highlighted piece has been installed at an end-customer and the packaging has been discarded.

4.2.12.1 Casting

Every mold used in the factory is designed so that a mold number will be visible on every piece through its whole lifetime. Identifying which casting cell the piece has gone through can thus be made until the piece has left the inspection. After a piece has left the inspection, the identification can be cumbersome depending on how much time that has passed since the casting. The molds can be used at several casting cell positions, and are not bound to one.

4.2.12.2 Drying

The dryers are never dedicated to a casting cell, which complicates the traceability. The mold number can thus never indicate which dryer that have been used. There is no marking on the piece that indicates where it has been dried. The ability to trace where a certain piece has been dried does not stretch beyond the operator moving it to a glazing cell.

4.2.12.3 Glazing

Standard washbasin production line

The casting cell dictates what glazing cell that has been used. If the piece has been casted in the northern casting cell it has been glazed in the northern glazing cell. Which glazing cell a piece has passed through can consequently be identified by the mold number until the piece leaves the inspection.

Bowl and cistern production line

All the bowls are manually stamped with a number, indicating which glazing cell it will pass through. The cisterns are however, not marked. Which glazing cell that a bowl has passed through can be identified through the bowls entire lifetime. Which glazing cell a cistern has passed through cannot be identified after it has left the cell.

High volume production line

The products manufactured in the high volume production line are divided between the three glazing cells. This means that the product code can be used to identify which glazing cell that a piece has passed through until the piece leaves the inspection.

MRC production line

There is only one glazing cell used at this production line. The mold number or the part number can thus identify which glazing cell that the piece has passed through.

4.2.12.4 Firing

There is no way to identify which kiln a VC-piece has passed through after the inspection. The inspection report, however, includes which kiln the piece has passed through. The report is not to any use for the identification of the piece since the only information the inspection-sticker holds is the time of inspection and the inspector identification. Kiln cars passing through tunnel kiln 20 are marked with a clearly visible color in order for the inspector to separate pieces from tunnel kiln 19. The FFC-pieces only passes through tunnel kiln 21.

4.2.12.5 Inspection

When an inspection report has been filed, a label acknowledging time of inspection and inspector identification is placed on the piece by the inspector. If the packaging is missing there is a possibility to estimate when the piece was manufactured if the label has been left intact by the end-customer.

4.2.12.6 Re-firing

Every time a piece have been repaired and is sent to the kiln it is stamped by the operator that has repaired it. With this stamp the inspectors can keep track of how many times a piece have been re-fired and also the performance of individual operators. A piece can at most be re-fired three times before it is discarded. There is however no way to know which of the two shuttle kilns that the piece has passed through other then when it taken out of the kiln.

4.2.13 The special handling of products for the large private brand customer

In order to be a supplier to the large private brand customer, all products that are delivered needs to be traceable. The customer demands that all pieces are equipped with a label identifying which week it was packed and sent to them. There should also be a marking on the packaging. The customer then supplies this information to Ifö, if a product is involved in a claim. Ifö is then required to answer to the customer regarding what actions they have taken in order to solve the problem with the product.

4.2.14 Sanitec Production System

In accordance with the LEAN principles all manufacturers within the Sanitec group is subjected to a yearly evaluation in order to assess the performance of each factory.

There are eight pillars that are evaluated by Sanitec personnel, each pillar consists of six levels where level 0 is the least favorable and level 5 the most favorable. Each step is divided into sub steps that state what needs to be achieved in order to reach that level. The factory needs to prove to the evaluators that significant improvements have been made since last year in order to reach the next level or sub-level. The eight pillars are as follows:

- Quality
- Employee involvement
- Working capital
- Standardization
- Team-work
- 5S
- Waste elimination
- Maintenance

In addition to these pillars Sanitec is interested in KPIs as well. The two that there is a focus on is global yield and first time approved. The global yield can be explained as a scrap measurement. The focus is a bit wrong in this measurement since a wasteful production system, i.e. a system with much re-fire, can still get a good figure. The second measure is much better from a continuous improvements point of view.

$$GY = \left(\frac{\#\ of\ casted\ pieces - (Casting\ loss + Inspection\ loss)}{\#\ of\ casted\ pieces}\right) + \left(\#\ of\ casted\ pieces - \left(\frac{First\ fire\ loss + Refire\ loss}{First\ fire}\right)\right) \quad (5)$$

$$FTA = \left(\frac{First\ time\ approved}{\#\ inspected\ pieces}\right) \quad (6)$$

5 Experiments

This chapter will cover the experiments that have been performed in order to establish what kind of marking methodology would be suitable for the traceability system. Several marking methods have been tested; both with the use of labels and with direct part marking.

Most tests have been carried out in a laboratory environment, and the dot peen technology has also been tested in the ordinary production line. This was done to ensure that the mark would survive the various process steps that a piece go through in production.

The authors and personnel at Ifö were only aware of a sanitary ware producers using wet slide bar code labels for their traceability needs, therefore extensive testing of other marking methods were required.

5.1 Labels

Two types of labels were tested; the wet slide bar code label which is currently used in some sanitary ware production lines at other manufacturers, and a ceramic bar code label with self-adhesive capabilities.

Since laboratory personnel carried out the tests manually in a laboratory environment, the application of the labels could be seen as ideal where in an automated production line the conditions would probably be less than ideal.

5.1.1 Wet slide transfer bar code label

The wet slide transfer label is a label printed with ceramic ink that fuses with the surface of the ceramic item in the kiln and allows for the bar code to be scratchproof and resistant against chemical attacks and high temperatures.

5.1.1.1 Tests

The label is applied by submerging a label into water or by placing a saturated sponge on top of the label. After approximately 30 seconds, the label film can easily be slid off its backing. After a slightly longer submersion, the film will detach itself from the release liner. A slab of fixative is then applied to the newly cast and still wet green ware. The label is then slid to its position onto the green ware. A sponge, a wooden spatula, or a thumb is then run over the label surface to remove any air or water trapped under the label.

A total of 12 samples with two bar code labels on each sample were tested. The samples consisted of samples where the label was applied to green ware, dried ware, glazed ware, samples which was over glazed, and samples that had the glaze wiped off from the label. The samples were dried in the laboratory, and then fired in one of the tunnel kilns.

5.1.1.2 Results

The time it took to manually apply a label was approximately 15 seconds. The results were excellent for the samples were the label was applied to green- and dried ware and then fired. There were no problems to read the bar codes of these samples, see *Figure 22*.
The results for the samples were the label was over glazed were poor and no read could be achieved, see *Figure 23*.
The results of the glazed samples were the glaze was wiped off the label was very good. For these samples there were no problems to read the bar code, see *Figure 24*.
The samples in which the labels were applied to glazed ware were of acceptable quality but the readability was low, probably due to light reflectance from the glaze, see *Figure 25*.

Figure 22 - Label applied to green ware, dried and then fired

Figure 23 - Label applied to green ware, dried, glazed, and then fired

Figure 24 - Label applied to green ware, dried, glazed, had the glaze wiped off from the label, and then fired

Figure 25 - Label applied to glazed ware, then fired

5.1.1.3 Conclusion

The wet slide transfer bar code label proved to be a very good marking method. However, the application procedure is very cumbersome and would be poorly suited for automated production. Hence, the authors and personnel at Ifö deemed this marking method to be feasible but unsuitable for regular production at Ifö's automated lines. For a less automated in which manual labor is more frequent, this marking method is very good.

5.1.2 Ceramic bar code label

The ceramic bar code labels consist of a ceramic substrate with a black ceramic ink, see . This type of label has been developed for marking of ceramic items before firing in a variety of extremely harsh environments. These labels are resistant to high temperatures, chemical attacks, and outdoor exposure. The labels that were tested had a 1D bar code (interleaved 2 of 5), but a variety of bar code symbologies, including 2D codes, are available from the supplier.
The label itself is fired onto the piece in the kiln, therefore temperatures of between 1100°C and 1250°C must be achieved, see *Figure 26*.

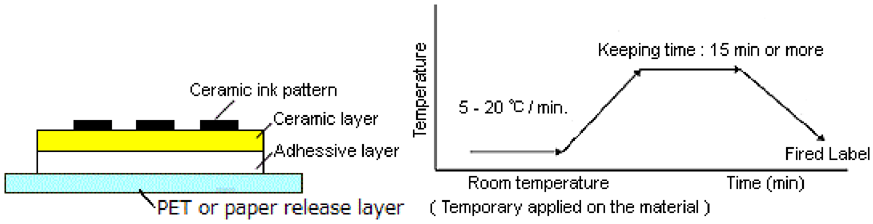

Figure 26 – Ceramic bar code overview

5.1.2.1 Tests

A total of four samples were made, the small number of samples tested was because only a few labels were provided by the supplier, further it was believed that the amount of samples would be enough to establish whether the label would work in an automated production line or not. Tests were carried out in which the label was applied to green ware (*Figure 27*) and dried ware (*Figure 28*). Two samples were over glazed, and one sample had the glaze wiped off the label after the glaze had been applied, see *Figure 29* and *Figure 30*. All samples were later fired in the tunnel kiln used for regular production.

5.1.2.2 Results

It took approximately 5 seconds to manually apply the label on the dried and green ware. The bar code labels on the green- and dried ware that were not glazed showed some damage after firing but were readable. The samples that were over glazed had significant damage to the bar code and could therefore not be read. The mark on all samples was also brittle and was easy to scratch off.

Figure 27 - The label was affixed to green ware, dried, and then fired.

Figure 28 - The label was affixed to dried ware, and then fired.

Figure 29 - The label was affixed to dried ware, glazed, and then fired.

Figure 30 - The label was affixed to dried ware, glazed, the glaze was then removed from the label with a wet sponge, and then fired.

5.1.2.3 Conclusion

The conclusion is that these bar code labels are not suitable because of the damage that occurred during firing. After talking to the supplier, they argued that a fixative applied to the ware before the label was applied should reduce the damage. This was however something that would become very difficult to automate in the existing production line and was therefore an approach that the authors and personnel at Ifö deemed inapplicable. The results were at a whole unsatisfactory and the ceramic bar code labels were therefore ruled out as a potential marking method.

5.2 Direct part marking

Direct part marking is a method for marking a bar code directly onto the product material itself. This provides a permanent mark that will enable the product to be identified throughout its lifetime. A deeper analysis of the method is explained in subchapter *3.5.4 Marking methods*.

5.2.1 Dot peen

Dot peen is a method for marking directly into the substrate material. It works by engraving the substrate with an oscillating pin, creating small dots in the substrate. This enables Data Matrix bar codes as well as text and numbers to be permanently marked directly onto the substrate itself. However, regular 1D bar codes cannot be engraved with this technology.

5.2.1.1 Tests

A total of ten samples were marked with between three and four Data Matrix bar codes on each sample in a laboratory environment. A washbasin was also marked after casting with three Data Matrix bar codes, see *Figure 32*, which

was then processed through the regular production line. This was done to establish how the bar code would be affected by the handling in the automated production line.
Seven samples were made from VC green ware, one sample was made from FFC green ware, and two samples consisted of dried VC and FFC ware.
The samples were marked with different marking force in order to establish what the optimal force to create a good mark is. The force used was 10%, 12%, 13%, 15%, 18%, and 20% of the maximum striking force.

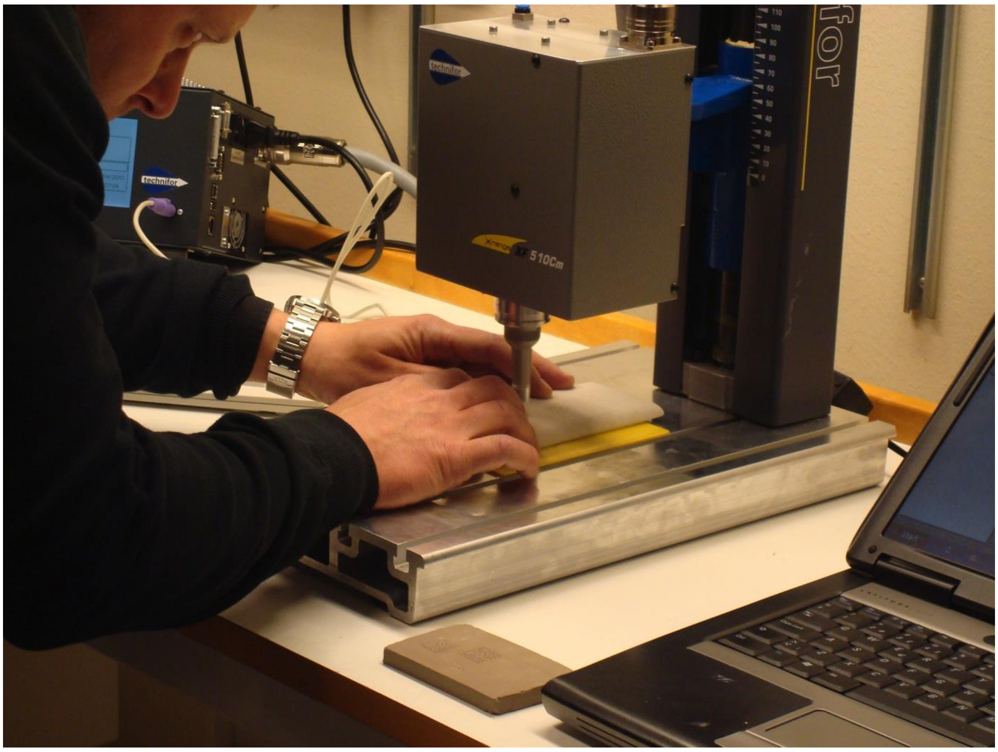

Figure 31 - Dot peen marking on a dried test sample

After marking the samples, see *Figure 31*, they were either:

- Dried and fired
- Dried and glazed with a standard layer of glaze
- Dried and glazed with a thin layer of glaze

Two of the glazed samples had the glaze wiped off from the mark.

The bar codes marked on the washbasin were marked with a striking force of 12 % on a surface that is not glazed, it is the surface that the washbasin stands on throughout the manufacturing process.

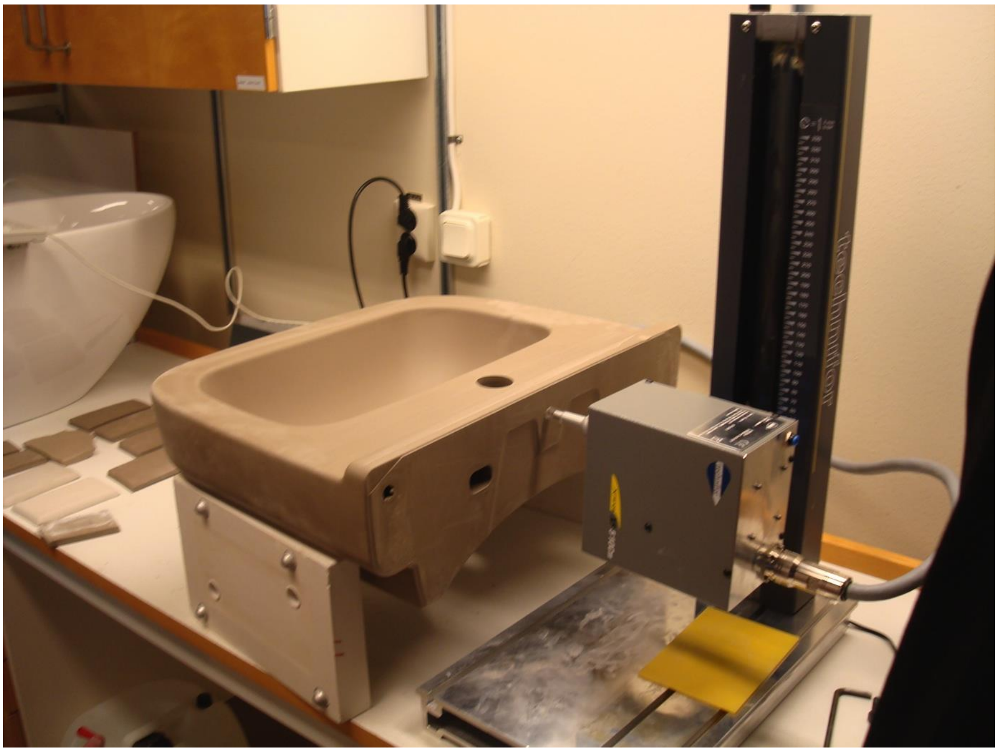

Figure 32 - Dot peen marking on a recently casted washbasin

The marks on the samples were read after each step to analyze how the readability and time to read was affected by the different processing steps. The readability and time to read test were made with a Cognex Dataman 7500 DPM hand-held reader as well as with a mobile phone camera with a bar code reader software for reference.

It should be noted that the distance between the stylus point and the surface of the substrate is very important since the stylus have a fixed impression depth. Therefore, some of the samples were marked with less distance than optimal and thus creating a mark that is shallower than if proper distance had been used.

5.2.1.2 Results

The marking of the Data Matrix code and the striking force number into the ware took approximately 9 seconds.

The sample that was over glazed with a thin layer in *Figure 35*, proved to be very difficult to read, even if some marks could be read after about 10 seconds.

The marks made on samples that were already dried were of excellent quality. Extreme caution must however be taken because the dried ware is very brittle. This can cause cracks and chips in the mark. The authors also tested the maximum striking force that is feasible, and it proved that with a striking force of 20 %, the sample would break.

The samples that were marked on green ware, dried and fired was easier to read and provided high readability rates, see *Figure 33*, albeit some of the marks with 10 %, 18 %, and 20 % striking force proved hard to read and the time to read was in some cases more than 10 seconds. The marks with 12 % and 13 % of striking force showed excellent quality, 100 % readability, and took less than a second to read.

The samples that had the glaze wiped off had poor readability rates, this can be attributed that glaze stayed in the Data Matrix cells which led to poor contrast ratios, see *Figure 35*.

The bar code marks on washbasin showed in *Figure 36* that went through the regular production line were of excellent quality and the read rate was 100 %, both with the Cognex reader and the mobile phone. The time to read was however irregular, between 0.5 seconds up to 10 seconds.

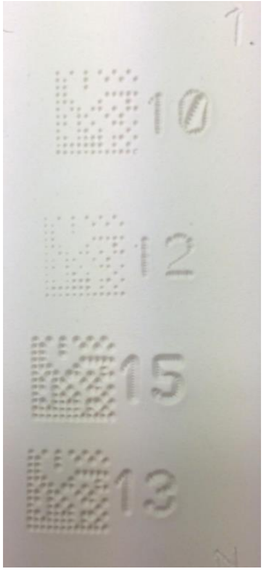

Figure 33 - Data Matrix marked on green ware, dried, and fired

Figure 34 - Data Matrix marked on green ware, dried, glazed with a thin layer, and fired

Figure 35 - Data Matrix marked on green ware, dried, glazed with a thin layer and wiped with sponge over the marks, then fired

Figure 36 - Washbasin marked with Data Matrix on green ware, dried, glazed, and fired

It must be noted that the time to read has a lot to do what lighting conditions that are present, since the reader relies on that contrasts is provided by certain illumination techniques. Therefore, the angle and distance between the bar code and the reader is of the utmost importance. The authors noted that the same mark could sometimes be read within one second and other times take as long as ten seconds. This discrepancy is probably due to the ability for the reader to provide different contrast ratios at different angles and distances.

5.2.1.3 Conclusion

The dot peen technology can provide excellent quality marks. Striking forces of 12 % -13 % has provided the best marks. However, the results show that no glaze should come in contact with the mark and that the bar code is preferably marked on green ware. The discrepancies in time to read are very disturbing since the specification of requirements states that the bar code should be read in less than one second. A Cognex 8100 reading equipment were later used in order to read the markings, and with this equipment the discrepancies were minimized, and a better time to read was achieved. Some care must still be taken to make sure that the reader is positioned at the proper distance and angle, in order to achieve a fast read.

Further, the dot peen technology is easily integrated in the existing production line and is not sensitive to environmental factors.

5.2.2 Laser engraving

Several laser marking methods are discussed in Appendix 2, and this experiment concerns the use of laser engraving to engrave 1D and 2D bar codes into unfired sanitary ware. Laser engraving vaporizes the substrate material with the use of heat, and because it is a ceramic material that is marked, the outcome of this experiment was very uncertain. Ceramic material are extremely resistant to heat, they should therefore be extremely hard to engrave in with the use of heat.

In this test a CO_2 laser with a power output of 60 watts was used and several speeds and power settings were tested

5.2.2.1 Tests

Table 4 shows four dried samples that were marked with a 1D bar code. Table 5 shows five samples of vitreous china green ware marked with the laser. Samples 5-9 were engraved with a 1D bar code and sample 9 was marked with a 2D Data Matrix bar code. Readability was checked with a Cognex Dataman 7500 DPM reader and a mobile phone camera with a bar code reader software.

Table 4 - Dried vitreous china ware marked with a 60 W CO_2 Laser

Sample	Bar code symbology	Power setting (% of 60 W)	Speed (bit/ms)	Time (ms) x runs
1	Code 128	40	400	8055 x 1
2	Code 128	40	400	8055 x 1
3	Code 128	40	400	8055 x 1
4	Code 128	40	400	8055 x 1

Table 5 - Vitreous china green ware marked with a 60 W CO_2 Laser

Sample	Bar code symbology	Power setting (% of 60 W)	Speed (bit/ms)	Time (ms) x runs
5	Code 128	40	400	8055 x 2
6	Code 128	70	800	4473 x 2
7	Code 128	70	1000	4086 x 2
8	Code 128	40	400	8055 x 1
9	Data Matrix	N/A	N/A	N/A

5.2.2.2 Results

The time it took to laser mark the green ware was eight to nine seconds, on dried ware it took 8 seconds as seen in *Table 5*.

The green ware samples that were marked as seen in *Figure 37*, showed a deep engraving, thus providing an excellent mark. During the engraving a lot of fumes and vapor were released which highlighted the importance of proper ventilation. The excellent results were a bit surprising to the authors and personnel at Ifö. Analyses were conducted in order to understand the phenomenon. The engraving could be attributed to the explosive release of water vapor that caused the clay material to be removed.
After drying and firing, *Figure 38* shows that the result was very good. The

readability was however very low, and could not be read with a Cognex DPM reader. However, reads could be achieved with the mobile phone.

Figure 37 - Sample 5 - Bar code marked with laser on green ware

Figure 38 - Sample 5 after drying and firing

The dried sample that were marked with the laser, showed not an engraving but a discoloration, providing excellent contrast in the bar code, see *Figure 39*. Personnel at Ifö were surprised by this result and analyses were conducted to establish the cause of the discoloration. The analysis concluded that the discoloration was because of organic material had been scourged (*Figure 39*), and the hypothesis was that this discoloration would disappear during firing due to the burn off of organic materials.

Figure 39 - Microscope snapshot of laser marking on dried ware

After firing, this hypothesis proved to be correct. As shown in *Figure 41*, the high contrast mark had disappeared only leaving small visible marks.

Figure 40 - Sample 1 – Dried VC marked with laser

Figure 41 - Sample 1 after firing

5.2.2.3 Conclusion

The results show that laser marking on dried ware discolors the material but it disappears after firing. Therefore, laser marking on dried ware is not suitable.

Marking on green ware resulted in a deep engraving, providing a good mark. The test also underlined the importance of proper ventilation, as well as laser safety considerations.

The contrast required for the reader would have to be achieved by illumination techniques. In the tests, the authors could not achieve a read on any of the green ware samples with the Cognex DPM reader but instead with a mobile phone with a bar code reader software. This is something that the authors seemed strange, however, the authors are confident that with proper reading and lighting equipment the readability would be good.

Therefore, further tests of readability and time to read with proper reading and lighting equipment will have to be made to ensure that the bar code meets the specification of requirement in chapter *7 Specification of requirements.*

5.2.3 Ink Jet

Two ink jet marking methods were discussed in subchapter *3.5.4.2 Non-intrusive marking methods*. The ink jet used for these experiments was a CIJ printer with high temperature ink. The ink that was used had been tested for up to 1000°C, and is made for the application on automotive catalyst converters. Therefore, tests with this type of ink where important to establish if the ink can be used in temperatures of up to 1205°C.

The CIJ printer was chosen because of its relatively large throwing distance, allowing for a printing distance in excess of 10 mm.

5.2.3.1 Tests

Four samples of green ware were marked to test the ink jet technology. Two samples were also marked on the underside (the side which the samples lay on) to establish how resilient the mark is to rubbing and scratching. The samples were then dried and fired. All sample were marked with two code 128 1D bar codes and two 12x12 Data Matrix 2D bar codes containing the information '1234567890'.
The samples were printed with different X-dimensions for the 1D bar codes and different cell sizes for the 2D matrices. This was done in order to see what X-dimensions and cell sizes could be read after the sample had shrunk during drying and firing.

5.2.3.2 Results

The time it took to print the bar code on a sample was under one second.

The samples showed in *Figure 42* demonstrate bar codes of excellent quality and contrast when applied to green ware, and it became even better after drying, see *Figure 43*.

Figure 42 - 1D and 2D codes applied by CIJ ink jet on green ware

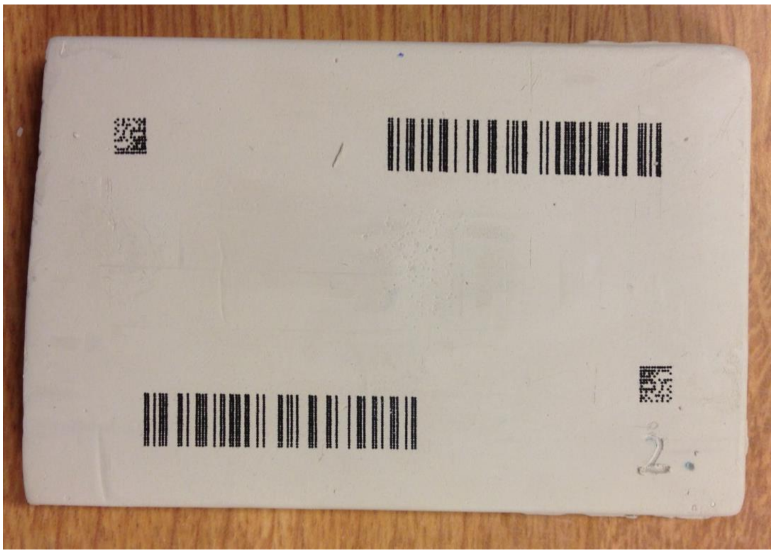

Figure 43 - 1D and 2D codes applied by CIJ ink jet on green ware, which was then dried

When applied to green ware, the ink was easily rubbed off since it had not dried properly. After drying, the mark was more stable and hard to scratch off. The marks printed to the underside, shown in Figure 44, showed some damage and only the Data Matrix codes could be read.

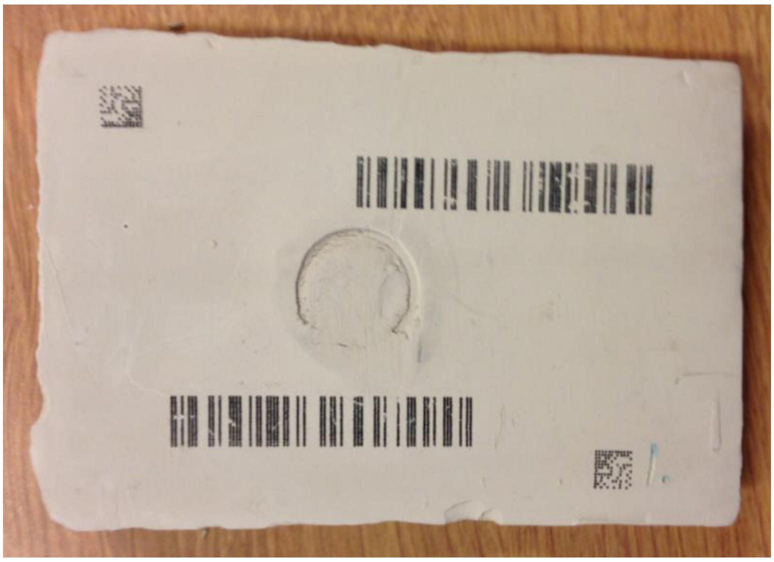

Figure 44 - 1D and 2D codes applied by CIJ ink jet on the underside of a sample

All the Data Matrix codes applied to the top surface were easily readable with a mobile phone. The 1D bar codes was however harder to read, only the codes with the standard (smaller) X-dimension was readable. It must be noted that only a mobile phone was used to read these code since no image based or laser reader was available at the time.

Figure 45 shows the samples after firing, where all the marks had disappeared leaving only a very vague mark.

Figure 45 - 1D and 2D codes applied by CIJ ink jet on green ware

5.2.3.3 Conclusion

The result showed that the printed mark is very sensitive to rubbing and scratching before it had dried properly. After firing the marks had disappeared which makes this ink unusable for this application. Other types of ink with other types of pigments, especially ceramic pigments, should be tested if this type of technology should be applicable for sanitary ware manufacturing.

The overall conclusion is that this technology could be suitable given the proper ink and if nothing could come in contact with the mark. However, further tests would have to be carried out to ascertain that ink jet provides the proper mark needed.

6 Analysis

In this chapter the main factors for an introduction of a traceability system will be discussed. The current situation will be compared with the available theory on the matter and will support the creation of a specification of requirements, both for the traceability system as a whole and for the marking method. These specifications will be essential during the talks with suppliers of the IT-system and the marking method in order to achieve an as good system as possible.

6.1 A traceability system's compliance with the Sanitec Production System

The introduction of a well-functioning traceability system will aid Ifö in their ambition to reach to a higher level in several of the pillars.

The ability to achieve better quality will be significantly improved if an automated traceability system is implemented. The ability to find root-causes, as well as finding them faster will improve, since the piece's paths will be evident in the traceability database. The traceability system's contribution to tools, like FMEA, is also worth to mention, since the input to these tools will be a lot more accurate with more precise data.

With a more precise data available, regarding performance of certain shifts or days etc., the employees could receive performance measures relevant to their production line or their shift, thus making them more aware of their importance for the overall production process. As it is today the performance measures available to the operators are not precise enough for them to understand their own importance for the success of the factory.

The traceability system will also enable tracking, which will be an important tool in order to reduce the working capital. Since there is issues today regarding the production reporting and the discrepancies it leads to, an optimization of the working capital will be hard to perform. The setup times differ a lot depending on which production cell that is highlighted, and this is an issue that needs to be solved in order to implement Pull to a larger extent than today. The traceability system's effect on the working capital should not be neglected though. The ability for the production schedulers to optimize the working capital would be significantly improved if more precise, and correct data was available to them.

The waste will be a lot more visible with a well-functioning traceability system, the time that value is not added to a piece will be clear, as well as work in process, and overproduction. Follow-ups on waste will be precise, and the resulting optimization will be based on facts. Follow-ups could also be made on certain shifts, and the re-firing operation, in order to optimize the performance of both the individual shifts and the re-firing process as a whole.

The possibility to optimize of maintenance is another aspect that will be improved with a traceability system. Problems with a certain rack, kiln car, or cell will be visible in the traceability system and dealt with immediately, predictive maintenance is also supported by the system on for example, kiln cars, where number of runs through the kilns would be available for the maintenance personnel.

6.2 The demand for traceability by Ifö's stakeholders

Ifö have no present requirement to be able to trace their products other than their ISO-9001 certification, and the traceability requirements the large private brand customer has on all of their suppliers.

The demand is not extensive in the industry as a whole if comparisons are made to, for example, the food industry. The drive for more traceability at Ifö is closer to the automotive industry, i.e. to support the findings of root-causes, and thus improve the ability to achieve continuous improvements of their operations.

6.3 The need of traceability at Ifö Sanitär Bromölla

6.3.1 Age

A certain product model's lifetime can stretch to 15 years. Ifö have a two-year warranty on all of their products, there are, however, some difficulties with the identification of when the product have been manufactured. This means that there can be several occasions where certain products actually have exceeded the two-year warranty but there is no way of knowing when it was manufactured. During the product's lifetime there can have been several alterations made both to the design of the product and to the process of producing it. The information sent back from a warranty claim can in that case be outdated and prompt actions from the quality control that should not be needed if a proper age of the piece was available. An example of such an action, is informing the production supervisor of a defect which the supervisor transfers to the process-support, which finally is considered as a defect that already have been taken care of.

In the light of these issues the need of properly identifying the age of a piece involved in a warranty claim is very important, both for the direct handling of warranty claims, and the indirect actions in the production lines, as a result of faulty information. An introduction of a new traceability system, if properly implemented, would to a large extent solve issues considering the age of a piece and thus minimize the number of invalid claims that are accepted as well as improving the ability for the quality control to make proper decisions.

6.3.2 Origin

The raw material that is used for making the pieces is bought from several distributers in Great Britain. This alone makes the traceability aspect interesting since the raw materials attributes can differ. Another aspect is the transport of the raw material and storage of it in the harbor of Sölvesborg. The raw material can have been contaminated with salt water during the transport and lost vital properties needed to achieve the wanted product. Since the inspection deals with every single piece that has gone through the kiln, nearly all of the pieces affected with a raw material problem should be discarded before they can reach the end-customer. However, if a proper built traceability system were in effect, production could be certain that none of the pieces based on that faulty raw material found their way to the end-customers.

6.3.3 Customization of items

Ifö made considerable changes to the production a decade ago, making it more automated. This meant that most of the manual workstations were removed in order to make room for the new automated production lines, which also meant a higher capacity. A highly automated production system requires high volumes since the cost of machinery is high and must therefore be highly utilized. The molds for the automated production lines and the tools associated with them are very expensive. Therefore, if the volumes are not large enough it is not profitable to manufacture the product. There are however some manual workstations left that handles low volume product types and special orders.

6.3.4 Errors and variations

The products that exit Ifö's production process should be kept to stringent quality standards. Even the smallest defects should lead to either a re-fire or a minor repair. An example could be small particles of an unwanted color that have discolored the piece with small dots during the transport through the kiln. The time between when the piece is formed in the casting-step until it is finally inspected takes a minimum of 32 hours. During this time, much can happen with the material, both during the value-adding steps and the time it takes to transport it to and from these steps. Since the number of operators has decreased considerably, due to the automated production lines, the time spent inspecting each piece during the process has also decreased considerably. In short, this means that it is harder to be sure of when and why a piece has a defect, if the type of defect does not have a known cause. With the help of a well-functioning traceability system these eyes are partially replaced by distinct information through the whole production process.

The traceability system would improve the conditions both for the quality control and the process-supports to find and manage the root causes to the defects.

6.3.5 The risk for illegal activities

The product's nature makes the probability for illegal activities rather limited. Many of the products are bulky and not prone for theft. The authors have not further investigated the matter.

6.3.6 Needs identified during the mapping of the production

In 2008, a decision was taken to further extend the use of the the ERP-system at Ifö, the system was not used in the production prior to this decision. The old system that was used in the production was to be phased out and the ERP-system would be implemented in the production as well. The transition to this system has however not been as smooth as they have hoped for.

A main problem that addresses the need for a traceability system is the discrepancies in the internal inventory stocks. Corrective changes into the system by production schedulers and production supervisors are executed frequently. There are many points in the production process that can prompt incorrect information into the ERP-system. For example, operators can type in incorrect number of pieces that has been casted or glazed into the system, the inspectors can type in incorrect part numbers in the inspection report, and the reversal of pieces can cause incorrect values in earlier process-steps. The mentioned actions are only a fraction of the inputs to the system that can cause incorrect values. In this case, a traceability system could serve as a security giving the person responsible of transferring the data into the ERP-system the possibility to assess if the data that is to be sent into the ERP-system is reasonable. Such checks are carried out today, but with a well-functioning traceability system these checks would be less cumbersome and more accurate.

6.4 The relative importance of traceability

In order to determine the appropriate level of traceability some factors needs to be addressed.

The value of the item differs a lot depending on product type, the main product types that are produced in the production lines should be subjected to a serial number, the less valued items, like cistern covers i.e. cistern lids, should not be included at all in the new traceability system. These lesser-valued items should be traceable by date of assembly, like they are today.

The criticality of a certain item is also a factor worth looking into. Since all items are exposed to water regularly the functionality of the item is vital. If the item cannot contain the water it is exposed to, much damage can be caused to the end-customer. To be able to trace these products, and what went wrong with them is important in order to avoid future failures of this sort.

The product life of the items produced in Bromölla can range up to 15 years, during this time many changes both to the design of the product, and to the production process can have been made. A longer product life also means that a lot more products are put into circulation, and thus the information that is attained from the claims can be outdated, and already dealt with in the production.

Since the main focus for the implementation of a traceability system is to gain better knowledge of the processes, and thus improve the quality, differences in amount of traceability between the product types is not recommended. This would mean exclusion of certain product lines for example, and since the production lines shares the tunnel kilns, information regarding this vital process-step would be unsatisfying.

6.5 Benefits with a traceability system at Ifö Sanitär Bromölla

6.5.1 Product recall

If a critical defect is identified on a product manufactured in Bromölla it becomes cumbersome to trace the affected products after it have left the factory. Since a piece can be re-fired in order to repair minor flaws, the piece may have looped several times in the factory before it is finally accepted by the inspection. There is currently no satisfying way to identify when a re-fired piece have gone through the previous process-steps. If a product is stored in the finished goods storage the package contains the date of assembly and packing. To add to the complexity, the bowl and the cistern that forms the water closet can have been manufactured on two completely different dates, making the identification of when one of those were casted even harder. Even if the root cause is identified and the number of affected pieces is narrowed down considerably it is still hard to find the pieces that are affected, especially for the water closets.

There are many costs that can be minimized with the implementation of a well-functioning automatic traceability system. If a critical error is found and the root cause identified and confined to a certain time period, the problem of identifying which pieces that was manufactured during this period remains. If the error is so severe that it cannot be handled through normal claim procedures, the recall would involve much more products than needed. This problem indicates two actions that cause recall costs. The first action is to invoke a mass recall on the affected product. The cost of making a mass recall on a large amount of products is immense. First and foremost a larger number of products recalled means larger costs in man-hours for locating the products, replacements of the recalled products as well as the handling of the recalled products. The second action is to handle the error through the normal claim procedures. This could lead to damage of the brand, which is hard to quantify, as well as more claims than needed. The costs included in a claim are both for the need of a service technician, with transportation and man-hours included, and the cost of the replacement item. The date of assembly and sorting is available on the package making the identification somewhat easier when the product is located at the wholesaler. If the product is located at the end-customer the package is usually disposed of and the date label removed, which makes the identification almost impossible.

6.5.2 Product liability

Since there is no permanent marking of the products today the ability to determine the age of a product is rather limited, as discussed in the product recall subchapter. The date of assembly and packing is available on the package as well as on a label on the product. This can help to identify the liability if the package and the label have not been lost.

The limitations result in problems in the handling of claims. Since the warranty to the wholesaler is two years, a lot of trust is put on the wholesaler since most of the claims are forwarded from them. The ability to determine the liability would improve considerably with the introduction of a traceability system. The identification number of the product could refer to a database where the time of assembly, or if possible even time of shipping to the wholesaler, would be clearly visible for the highlighted product.

6.5.3 Quality- and process improvements

Most of the pieces with defects are identified in the inspection and the production line is vocally informed about these defects. Information is also gathered from claims and if the handling of claim information is improved, it will be an important tool in the future for quality- and process improvements. This information is then used to make changes into the production process. Statistics from the inspection area can be used to analyze design and process changes. The process of attaining the needed information is however cumbersome and somewhat inaccurate since the only information that is available is when the piece has been inspected. The piece needs to be backtracked from the inspection in order to get an approximate time frame for the different process steps.

With an automated traceability system where each piece has an individual identification number the follow-up on design and process changes will become much better and less time consuming. Today only one defect is reported into the ERP-system. This means that a lot of defects are lost in the follow-up because of the time it takes to submit the information. Information regarding all defects are however vital for follow-ups of process changes for example. A database meant for the traceability system could hold this information and only send the most severe defect into the ERP-system. It goes without saying that no unnecessary time should be spent on gathering the needed information, this time should be spent on adding value to the product through design changes and process improvements.

6.5.4 Proof of quality and origin

The Bromölla factory supplies the large private brand customer with washbasins and vanity tops. In order to be a supplier to the customer the supplier needs to fulfill their requirements and reach their standards. One of these are to be able to trace the root cause of a defect and report back to the customer what actions have been taken in order to correct this defect. Today, pieces intended for the customer are marked with label bar codes in order to trace defects in a satisfactory matter. The use of a production wide traceability system where every piece ever casted is recorded would achieve a far superior traceability than the current solution.

6.5.5 Logistics

If the traceability system is widened to also include the warehousing the ability to trace a product when it has left the factory significantly increases. If the identification number on the piece is applied on the package of the piece the traceability system could keep track on exactly when and where a certain piece was shipped. The id-number could also serve as a final check that the piece that is shipped is actually the product that it is supposed to be sent. Today, there are bar codes on each piece's packaging acknowledging which product it is and the piece have a label acknowledging when it was inspected. If the id-number of the piece would be visible on the packaging the operator could scan the bar code with the id-number and in that way register where the product has been shipped. The same information that has been sent into the ERP-system before could still be supplied by the traceability system to the ERP-system since the part number already has been recorded in the traceability system.

The internal logistics aspect should not be forgotten. With a traceability system, recording all the pieces' path through the processes, accurate information can be retrieved for follow-up on a certain day or shift. These follow-ups can for example be on how much lead-times and changeover-times differ between different days and shifts. This information can then be used in order to achieve a better and more effective production.

Instantaneous information would be available to the production supervisors in order to respond fast to problems in the process, this type of information is not available to the production supervisors today. It would also be possible to keep track of the WIP-stocks for each process-step.

6.5.6 Security

The internal inventory stocks in the production are a large issue since much time is put on correcting these errors. The discrepancies also induce indirect problems for the production, if the numbers cannot be trusted the persons handling scheduling and supervising becomes invaluable to the factory. The experience of these persons keeps the factory running and if they are to be replaced the transition period will be hard to manage.

The discrepancies also cause other problems that need to be handled by production supervisors and production schedulers. Since there is no specific marking on the pieces today the only information regarding the pieces is the number of each product type. If a piece is lost during production it is the operator that needs to inform the production supervisor of this loss in order for the supervisor to make corrective actions into the ERP-system. If this is not done, the material for the piece and the piece will be locked at that operation until corrected. The ability of finding out what has happened and when decreases significantly if the loss is not reported immediately. With a traceability system this would not be a problem. Each production supervisor could keep track of all the pieces that have been casted and if a piece have not reached a point where it should be, the reason why can be identified the same day. The person responsible for a specific piece can also be identified through the time when it was last recorded into the traceability system, and thus supply the production supervisor with information on what has happened with the piece.

6.5.7 After-sales

The warranty claims are an important issue that already has been covered in the subchapter *6.5.2 Product liability.*

Another benefit in the after-sales is that the customer service can retrieve information on known issues with a certain model during a certain timeframe. With this knowledge the customer service could make good judgments regarding a certain claim and forward this information to the service technician that is sent out to the customer.

6.5.8 Accounting

The discrepancies in the internal inventory stock also affect the accounting department, since the discrepancies needs to be assigned to the different part numbers and the result sent to the business group. A traceability system would make the costs associated with certain products much clearer and distributing costs on different cost centers easier. Today, activity-based-costing is not carried out at the factory and even if it would, the result of it would not be accurate due to the large discrepancies. A well-functioning traceability system would support the transition to activity-based-costing in the future.

6.5.9 Benefits identified during the mapping of production

During the mapping some benefits not mentioned in the literature was identified. The work tasks of several of the production staff could be altered if a traceability system was introduced. Today, operators manually check how many pieces are casted and glazed by writing down the number of casted and glazed pieces from the robots' PLC's. This is time consuming and can cause erroneous reports on how many pieces that have been casted or glazed. For the production supervisors, much time is put on finding out when a certain piece have been in a certain process-step and corrective actions to the WIP stocks are made in order to make sure production is running smoothly. All of these non-value adding tasks need to be reduced to a minimum in order for the staff to focus on their core competences and their actual work tasks. With an AIDC traceability system, there will be no need for manual production reporting and the extensive use corrective changes carried out by the production supervisors due to stock imbalances. It will also enable the quality control to be a lot more accurate when dealing with claims since the history of that piece is recorded and can easily be analyzed. The information exchange with the production lines becomes a lot better if the actual time of production is available.

All pieces that are produced in Bromölla pass through one of two inspection zones and all pieces induce an inspection report. This means that there is a great potential for good follow-ups on different parts of the production. In order to achieve good follow-ups the reporting needs to be improved in accordance with the implementation of a new traceability system. In order to achieve a good basis for quality improvements all defects needs to be recorded. Due to time limitations, only one defect is supplied today. Which defect that is supplied to the ERP-system is determined according to a ranking. The reporting can however deviate from this ranking when there are major problems with a certain defect. The problem with this approach is that a lot of valuable information is lost. When the ranking is abandoned it seems like there are not any problems with the other defects that might be ranked above the typed in defect. The fact that only one defect is typed into the ERP-system a major limitation that needs to be addressed. All defects can, for example, be recorded in the traceability system, with the gravest defect, according to the ranking, supplied to the ERP-system. The traceability system can then be used in order to achieve quality improvements. Another solution might be that the defect information is not sent at all into the ERP-system, it is just recorded in the traceability database, since it is mainly the production that are interested in these defects.

The follow-up on claims from customers is another matter. The Bromölla factory produces sanitary ware for many companies within Sanitec, and the ability to attain an id-number for a claim will differ a lot depending on where the product is located. The claim information that could be used to make quality improvements would to a large extent need to be for the Ifö brand, since Ifö in that case directly could instruct their service technicians to supply this information. Gathering id-numbers for a claim that involves another brand will be more cumbersome. The other brands would in that case need to instruct their service technicians to supply information that only is available on a rather limited set of products. Such an implementation is not likely, however, when a product has extensive problems and a lot of claims tied to it, the other quality control departments could supply the id-numbers.

The ability to handle claims is also dependent on what claim information that is given. As it is today the claim information that reaches the quality control is of poor quality. Even if the service technicians are experienced and submits good forecasts of what is to be handled the information is still inaccurate. The information attained from the CRM-system is a lot more accurate since it is typed into the system after the service technician has repaired or replaced the product. If the current talks of incorporating the CRM-information go as planned, the opportunities for the quality control to make good judgments regarding the claims will be much better. What is important for the production is that the relevant claim information is supplied to them. This includes the id-number, defect type, defect position, and if possible also a picture of the defect. This is a must in order to use the traceability system in a satisfactory way for claims, if not supplied the ability to solve root causes will be very limited.

The inspection handles a lot of pieces every day and information is supplied by the inspector for each and every piece into the ERP-system. Since all information is typed in on a keyboard it takes a lot longer than it needs to. An introduction of a traceability system should include a reformation of the inspection stations. The typing on a keyboard should be replaced by a far more efficient solution. The time spent on typing in the information should be spent on inspecting the piece properly and minimize the number of pieces that is incorrectly accepted.

6.6 Type of traceability needed at Ifö in Bromölla

During the discussions with the production management at Bromölla, as well as during the mapping of the production, it has become clear that there is a considerable need for an active traceability system. The system is not to be used as a simple tracking system, where the location and type of product is visible, but rather as system that systematically is used by different parts of the company in order to improve the quality of the products and the production. The tracking of where a certain product is at the moment is not as important as where it has been and when it was there. This information improves the ability to do follow-ups in all of the production lines during very specific timeframes.

The production supervisors and the process-supports should use the system in order to find root causes of defects either attained from claims or from the inspection. The quality control will be a lot more precise in their information exchanges and the ability to make accurate follow-ups will be a lot better. The production schedulers will be able to trust the numbers attained from the ERP-system and completely change the way they work and instead adjust production parameters. In the current state the schedulers need to double-check the output of the inspection with the number of casted pieces in each cell, which is information that may or may not be trustworthy. Optimizations of the production scheduling are hard to make due to the lack of trustworthy data.

The follow-up on re-fired pieces is not adequate in the current state. The inspectors can keep track of how many times a piece have been re-fired and discard it after the third time it has been re-fired. There is however no information available in order to make follow-ups on, for example, number of times a product usually needs to be re-fired. With a traceability system that keeps track on how many times a certain product have been re-fired the process of re-firing could be further explored and improved.

6.7 Appropriate design of a traceability system at Ifö Sanitär Bromölla

The design of the traceability system needs to be discussed in order to achieve an as well-functioning system as possible.

6.7.1 Breadth of the system

First of all the breadth of the system needs to be analyzed. The only information that is sent into the ERP-system by the operators at the production lines is number of pieces casted and glazed. The operators locally record all information regarding process changes. The traceability system should prompt a minimal number of changes in the ERP-system. Ideally the same information as today is sent into the ERP-system by the traceability system and the information needed to trace a piece and improve the processes is kept in the traceability system.

Information that is needed in order to trace a piece in a satisfying way:

- Point in time when the piece went through a certain process-step.
- The identity of the cell where the piece is processed
- Possible connection with another piece, for example, bowl and cistern
- Possible connection with a carrier, for example, kiln car
- Part number
- Mold number
- Type of defect
- Location of the defect
- Assessment, if the piece is accepted, re-fired or discarded
- Inspector that inspected the piece
- Operator that handled a piece

The point in time and identity of the cell is needed in order to trace the piece's path through the factory. The connection is needed since the cisterns and the bowls can be produced during completely different points in time. The connection between pieces would in that case be done during the assembly in order to keep track of when the product, the water closet, was finalized. The connection with a carrier might be needed in order to follow the piece through the whole production process. Between the casting phase and the glazing phase as well as between the glazing phase and the inspection the piece travels through areas where an industrial robot is not present. An optimal reading location will be hard to find since all product types are placed in different ways on the kiln cars. A solution to this problem could be to mark all the carriers as well and make them act like "parents" to the pieces, which means that all information that is stored on the carrier id-number is mirrored to the piece id-number, until the pieces identification number can be easily read again. The part number is needed in order to distinguish the pieces in the database. The mold number, inspector, type of defect and location is obviously needed in order to conduct follow-ups on certain parts of the production and improve them.

Quality improvements are carried out at the production lines with the quality control mainly supplying information to the lines about issues and conduct revisions. The need to incorporate process data into the traceability system before the inspection, with the part number as an exception, is thus not vital in order to make quality improvements. The process-supports keep their own records of process-data and with the lot-tracing data (point in time, location and connection) available, the root causes are more likely to be identified.

The issue of how the traceability system should interact with the ERP-system also needs to be addressed. The proposed breadth of the traceability system includes all information that currently is sent into the ERP-system from the production lines and the inspection. The input of incorrect information into the ERP-system today becomes cumbersome to handle especially if it is not identified immediately. The inspectors types in information directly into the ERP-system, they are however not directly affected by the problems incorrect information in the ERP-system causes. The traceability system could in this case act as a buffer of information before it is sent into the ERP-system, where the production supervisors that are directly affected by mistyping are the ones accepting the information and transfers it into the ERP-system. The limitation of just adding one defect into the ERP-system affects the ability to make accurate follow-ups. The traceability should be able to handle all defects but just send the most severe into the ERP-system.

6.7.2 Depth of the system

The piece starts to exist as a product when it is casted and it is from that point it ideally should be traced with a marking. If the point in time when a piece was cast is available, the slip preparation is able to trace what clay batch the piece consists of. This means that the raw material can be traced back to when it was acquired from Great Britain. The traceability will then ideally stretch until the product leaves the factory. If each piece's id-number is registered when it is shipped, the point in time and recipient customer could be available in the traceability system. The traceability beyond this point in time is dependent on the customers and if they are interested in access, or granted access by Ifö, to the traceability system. The traceability system should be active in terms of quality improvements of the products, and the focus will be on tracing process-steps in the factory. Other applications like product recalls would of course be significantly simplified if the customers, i.e. the wholesalers, had access to the parts of the system.

6.7.3 Precision of the system

Since the traceability system is to be used frequently in terms of quality improvements, what is to be traced needs to be very precise in order to be helpful. Ifö's production system makes it possible for the same products to have completely different paths through the factory. In the light of this complexity the need of being able to trace individual pieces are evident. If the precision would be decreased to only include batches of pieces instead the information available for quality improvements would decrease. In that case the need of reading points would decrease since there would be no way to distinguish individual pieces from each other. The end-result from a quality improvements perspective would not be that far from the current situation. From a product recall or product liability perspective the result would of course be much better than the current situation.

In order for the system to be used as a quality improvements tool, the lot-process linking needs to be on a piece-level in order to distinguish different paths through the production system. Each piece should ideally be equipped with an identification number in order to achieve the desired traceability.

6.7.4 Physical lot integrity

The precision has been discussed earlier in the subchapter *6.7.3 Precision of the system*. With the precision on a piece-level the integrity of the lots, in our case the pieces, needs to be addressed.

Lot mismatching can be an issue depending on what production line that is highlighted. For the standard washbasins line, the molds are rarely changed and when they are the PLC that handles the robot is programmed to know which product type is casted in each casting cell location. The part number could be supplied to the traceability system by the process-support every time the molds are exchanged. It can however be a problem in the MRC-line where mold changes are carried out more frequently. In that case the changes into the traceability system would be more frequent than for the other lines, and could cause lot-mismatching problems. Lot-end mixing should not be an issue since the robot carries out the same routines every time. Lot-sequence mixing will not be an issue since the traceability system should not include the manual workstations where there is a risk of failure in maintaining prioritization.

6.7.5 Reporting

In order to handle the large amount of data that needs to be collected from all of the production lines, a database is required. The information that has been discussed in the subchapter *6.7.1 Breadth of the system* should be connected to each and every identification number introduced.

The database needs to be accessible with the currently used data analytics tool. A replacement would further complicate a transition to this new traceability system.

7 Specification of requirements

In this chapter the specification of requirements for both the traceability system and the specific AIDC method will be declared. The subchapters will highlight the most important needs and technical requirements. The extensive specifications can be found in Appendix 1.

7.1 Specification of requirements for the AIDC method

The specification of requirements for the AIDC method is very important to establish since the specific processes puts high demands on the AIDC method. The specification will therefore try to cover all the specific requirements that the processes at Ifö puts on the AIDC method. This will provide for high functionality once the entire system is implemented.

7.1.1 Needs

The data carrier would have to be applied by automated equipment, since no personnel is available for this operation. The application should preferably be applied on moist green ware, as soon as the piece has been casted. This is to ensure traceability from when the piece is casted.

The data carrier should not be sensitive to humidity, minor mechanical stresses or extreme temperatures. The casting cell has a relative humidity of approximately 70 % and the kiln reaches temperatures of up to 1205°C. Mechanical stresses can occur in the handling of the piece in its green and finished states.

The reading (data capture) technology needs to provide near instant time-to-read and high readability. It will also have to consist of fixed mount and hand-held readers. The fixed mount readers will have to be able to ensure a read on the command of a robot, sensor or human trigger. The data output from the readers should include time and date, location, and the information contained in the data carrier. Further, the reader will need to communicate in real time with the traceability system.

7.1.2 Technical requirements

- The data carrier (bar code, RFID, or other) should be applied on moist green ware by the use of automated equipment
- The data carrier should be readable by data capture technologies (readers) throughout the process and on the aftermarket

- The data carrier should provide human readable information as a backup
- Shrinkage of the material during drying (3,5 %) and firing (10 %) should be accounted for
- The data carrier should withstand temperatures of up to 1205°C for 16 hours
- The data carrier should be permanent
- The reader should have a read rate of >99 % and a time-to-read of less than one second with the data carrier
- The readers should consist of both fixed and hand-held readers
- The reader should be able to communicate with a PLC, work independent, or via a trigger (sensor or manual)
- The reader should be able to communicate seamlessly with the traceability system. Output data should at least include time and date, reader location, and the information in the data carrier

7.2 Specification of requirements for the traceability system

The specification of requirements is a crucial step in order to achieve a successful implementation of the traceability system. This specification will both deal with functional and detailed technical requirements.

7.2.1 Needs

The recording of data needs to be fully or to the largest extent, automated. There is not enough time for manual intervention by the operators on all of the pieces that passes through each production line.

The recording of data for the traceability system must affect the production as less as possible. This means that the production must continue even if data cannot be retrieved.

The whole production process is of interest and thus the data needs to start to be recorded as soon as possible in the process. The control points in the process should make sure that a piece's path through the production process can be analyzed.

There must be redundancy in the system, so that operators and production supervisors can make corrective changes, before the information is sent to the ERP-system.

7.2.2 Functional requirements

- Physical process fully or to the largest extent, automated
- The marking should be placed on the piece after it is casted and before it is dried
- The flow of goods cannot stop if the marking is not read
- If the marking cannot be automatically read there must be a redundancy system available to the operator
- The data is to be recorded in a database where the information is connected to every piece's identification number

7.3 Concept for the standard washbasin production line

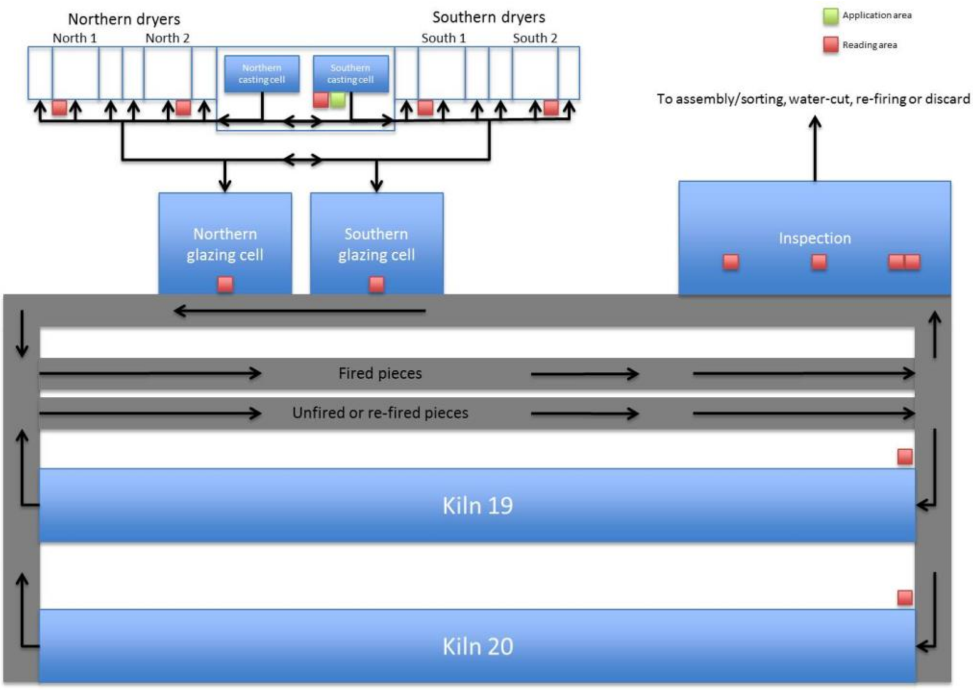

Figure 46 - Possible solution for the standard washbasin production line

A possible solution to the placement of readers for the traceability system is described with help of the production line map for the standard washbasins, see *Figure 46*. This information was also handed to the suppliers.

The red markers pinpoints approximate positions where the readers most preferably would be placed in order to be able to fully trace a piece's path. The green marker pinpoints where the piece most preferably would be marked with some kind of marking.

Immediately after the industrial robot has carried out additional work on the piece it should be marked, either by the robot or with assistance of the robot. The reading of the marking needs to be carried out as soon as possible after the piece has been marked. The reader should then supply the database with the identification number, the time and which reader that supplied the information. Finally the industrial robot places the piece on the rack.

For the next reading there is no industrial robot that can carry out that action. The probability to find a placement of the marking that is functional for all types of pieces and that can be easily read from a stationary reader is not high. A solution to this problem could be to assign identification numbers to the racks and kiln cars as well and connect the pieces identification numbers to them. This would mean that only the rack's and kiln car's identification number would need to be read and thus make the reading of all pieces less cumbersome. The rack would then be read when it entered the dryer.

In the glazing cell either the industrial robot would read the identification number and glaze the piece. When it transfers the piece to a kiln car it needs to register this switch as well. Doing this would result in that a new connection is made, this time to the kiln car.

8 Proposal and alternatives

The proposal will include the ideal solution in order trace a piece from casting, until it is assembled and sent to the finished goods warehouse. First the proposed system design is presented, the most suitable marking method on the pieces is also proposed, and a possible solution of reading the racks and the kiln cars.

8.1 System design

This part will describe the flow of information and pieces, with all the concerned marking and reading points. It will be based on the general flow of goods and information since all the production lines contains the same kind, and order, of processes.

The piece is casted, and when finished an industrial robot retrieves it, places it on a rack, and carries out minor operations on the piece. The marking with an individual serialized identification number, making the identification "tight and accurate", will be added to these minor operations. The marking of the piece will thus be carried out before the piece is put on a rack. The piece and rack will be linked in the database, enabling that only the rack would have to be tracked, thus providing all the movement information between casting and glazing of the individual piece. The rack will be equipped with a permanent marking, giving the individual rack an identification number. Each rack position in the casting cell and each dryer will also be marked with an identification number. Each forklift that transports the racks from casting to drying and glazing will be equipped with a reader. This will enable the operator to scan first the rack position and then the rack, linking the rack to a certain position. When the operator puts the rack into the dryer, the dryer identification mark will be read, thus providing the information on which rack was put in which dryer at what time.
When the rack is taken from the dryer, it is transported to a holding area or directly to the glazing cell. In the glazing cell, the robot will take the piece and hold it before a reader, which reads the piece's identification number. The robot will then perform its glazing operation and finally put the glazed piece on a kiln car. In this stage, the piece and kiln car will be linked in the database. This will be done by marking all the kiln cars with an identification number. The kiln car's identification number will be read when it is positioned at the glazing cell.

The kiln car is then transported into the kiln where its identification number is once again read. Giving information on which kiln it goes through and at what time. This information is linked to the individual piece in the database. The kiln car will reach the inspection where all the individual pieces are dismounted from the car. Here, the pieces will be inspected and the individual piece identification number is read. When the piece is read, all the information previously stored in the database will be provided to the inspector, enabling him to make a plausibility assessment if the information is correct. The inspector then classifies the piece as approved, need re-fire or if it should be discarded, with all defect types and defect locations.

The pieces that needs re-firing is placed on pallets, and when the pallet is full, a label is printed out which will carry a location code as well as an identification code that is linked to the pieces that is on that pallet. The approved pieces are also placed on pallets, but the approved pallet is only marked with a location code that will guide the AGV to the designated location. The re-firing pallets are transported to the re-firing WIP stock where it awaits an operator to retrieve it. When the operator retrieves it, he reads the identification code and input a location code into the database on where he will place the pallet. This will allow for the pieces to be tracked in the re-firing WIP stocks. The operator in the re-firing retrieves the pallet with pieces that are in need of re-fire, from the re-firing WIP stocks and transports it to the repair cell. Before the piece is repaired the operator reads the piece marking, which register it at the station and retrieves information regarding the defects to repair. The repaired piece is then re-fired and inspected again, according to the same procedure as mentioned earlier.

The approved bowls and cisterns are transported to an assembly cell where a robot reads the bowls identification number and the cisterns identification number. The bowl and cistern are then assembled and a link is created in the database creating a new product. A connection is also made between all pieces that are placed on a certain pallet, in order to keep track on where certain piece is placed in the finished goods warehouse. A label with the connection between the pieces is placed on the pallet, and is later read by the forklift operator when the pallet is to be stored in the finished goods warehouse.

8.1.1 IT-system

The authors do not recommend any specific IT-system but creates a generic description of what data should be stored and how it should be used. This is to ensure that no limits in coding languages, connectivity and interfaces are made. The authors realize that this is a subject were they do not have the crucial technical knowledge needed. However, some important consideration must be taken:

- The IT-system should be a closed stand-alone system, since no one outside of Ifö is directly affected by the traceability system.
- The interconnection with the ERP-system is crucial to the success of the system, and therefore, the new traceability IT-system should have the same operational stocks as the ERP-system. This means that the information stored by the traceability database should be exported in proper intervals to the ERP-system, allowing other parts of Ifö to still get all the information they do today. All other information stored in the traceability system is for the factory's personnel to use in order to help them to find root causes which results in process- and quality improvements.
- The IT-system should be interoperable with the CRM-system, meaning that the information supplied by the service technicians can be exported into the traceability system.
- The system should also be interoperable with the data analysis tool currently used at Ifö.

This information together with the information provided in subchapter *7.2 Specification of requirements for the traceability system,* should provide an IT-system developer with most of the information required to build the infrastructure of a traceability system.

8.1.2 Marking and reading of the pieces

8.1.2.1 Marking method

By a thorough analysis of the production processes at Ifö, and an extensive experimental analysis, the authors have concluded that the most suitable marking method is:

- Electro mechanical dot peening of 2D Data Matrix bar codes directly into green ware

This choice of marking method will allow for a seamless integration into the existing production process, achieve a permanent mark that can withstand all the requirements that were specified, require minimal maintenance, and provide for good readability. The Data Matrix will be of 12 x 12 cells enabling it to store eight numbers. The numbers will be serialized and act as a license plate to a database. The numbers will also be marked in plain, human readable format in conjunction to the Data Matrix for the purpose of redundancy.

8.1.2.2 Reader technology

The dot peen technology is only capable of marking 2D bar codes, specifically the Data Matrix code. This has an impact on the choice of reader technology.

The DPM Data Matrix code put specific demands on the type of readers that can be used. Therefore, the choice of reader is:

- Image-based reader with Data Matrix and DPM support

The technology can be used in a hand held device or as a fixed mount reader, which was outlined in chapter 7 *Specification of requirements*.

8.1.3 Marking and reading of the racks, rack positions and dryers

8.1.3.1 Marking method

Through the analysis and careful evaluation of the racks and their movements, the authors have concluded that the most suitable marking method is:

- Permanent 1D bar code labels

The racks do not go through any extreme processes. They are only affected by temperatures up to 90°C and a relative humidity of 70 %. The racks are also relatively few in numbers. Therefore, the authors conclude that 1D bar code labels will suffice.

8.1.3.2 Reader technology

The choice of 1D bar code labels enables the authors to choose a reader technology that is cheaper and simpler than the image-based reader used for the reading of the pieces. The forklift operator needs to be able to see which rack, position and dryer that he has scanned and therefore linked. Therefore, the choice of reader technology is:

- Hand-held PDA with a built-in laser scanner

This technology will enable the forklift operators to scan the bar code on the racks, the rack position identifiers and the dryer number while seated in the forklift and assure the operator, by visual confirmation in the PDA, that the proper link has been made. It will also enable the operator to make changes and correct errors that has been made.

8.1.4 Marking and reading of the kiln cars

8.1.4.1 Marking method

The kiln cars are subjected to maximum temperatures ranging from 250°C on the cars underside to 1205°C on the top of the kiln car. These extreme temperatures mandate the use of high temperature bar code label. The conclusion is that the most suitable marking method is:

- Permanent 1D ceramic bar code labels

These labels will be permanently attached to the side of the kiln car.

8.1.4.2 Reader technology

The kiln cars identification contained in the bar code will be read at the glazing cell when it enters, and when it enters the kiln. Therefore, the authors recommend that the most suitable reader technology is:

- Industrial grade fixed mount laser reader

Since the kiln cars' movement is fixed by track and AGV routes, fixed mount reader will enable optimization of the scanning distance, angle and placement of the reader in relation to the bar code.

8.1.5 Inspection

The information that is supplied to the traceability system is vital in order to find root causes. Therefore, changes to the inspection report are needed as a part of the introduction of a new traceability system.

First of all there needs to be changes to the role that the inspector has today, i.e. the supplier of all tracing data for a piece. With the introduction of the traceability system, the inspector's role will be to check if the data recorded on the database is reasonable, and then supply the system with the outcome of the piece, the defect type, and the defect location. In order to keep track of pieces before they are placed in the finished goods warehouse the inspector should also submit what composition the pallet has. The label that is placed on the pallet today with destination data should be expanded to also include the connection between pieces on the pallet. With this information available on the pallets, the current location of an individual piece can be retrieved from the system.

All defects should be submitted to the system, and on order to achieve this, the inspection reporting protocol needs to be replaced. The inspection stations should be equipped with touchscreens, with a keyboard available if any inconsistencies are found in the recorded data. The submittal of defect locations will be made by marking the location on a figure of the piece. This will decrease the time it takes to submit defect types and defect locations considerably, enabling for all defects to be reported and more time available to inspect the piece. Figures that display the concept of a new inspection reporting protocol can be found in *Appendix 3*.

8.1.6 Claims handling

The information supplied to the quality control at the factory today is lacking. Therefore, changes in the information flow from the service technicians to the factory quality control, needs to be done.

When a case is closed in the CRM system, information that should be supplied to the traceability system and labeled as claims are:

- The piece identification number
- Defect type
- Defect location
- (Pictures)

From this information, quality control personnel can trace the specific pieces' history, in order to find root-causes for the claim. This will allow for process improvement that leads to fewer defects arising after the inspection.

8.1.7 Input to the system

During the piece's path through the production process it needs to prompt the registration of data into the traceability database. The common flows and what input is required from each step can be found in *Figure 47*.

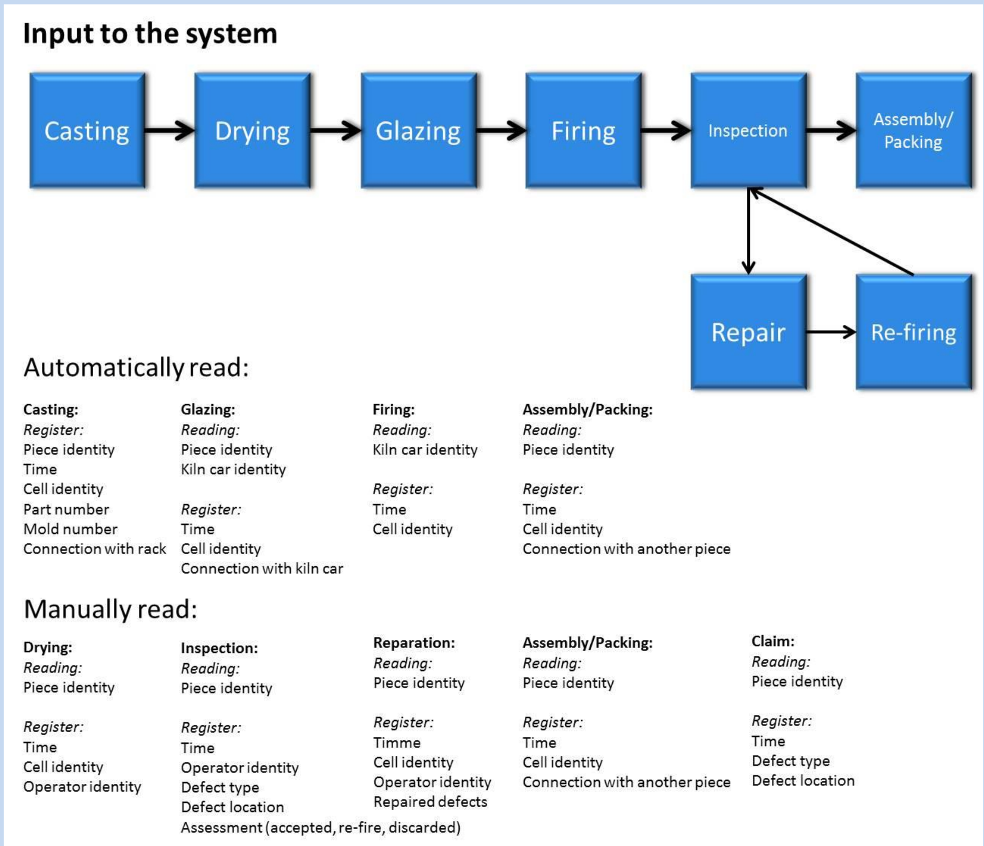

Figure 47 - Input to the traceability system

8.1.8 Output from the system

The system will supply information to the business enterprise system, and the database must be readable with the data analysis tool currently used at Ifö, so that the personnel can conduct their business. The information needs to be accessed from the inspection station during the inspection, the repair station in order to read the inspection report, and the production lines in order to check the instantaneous data and correct it if needed.

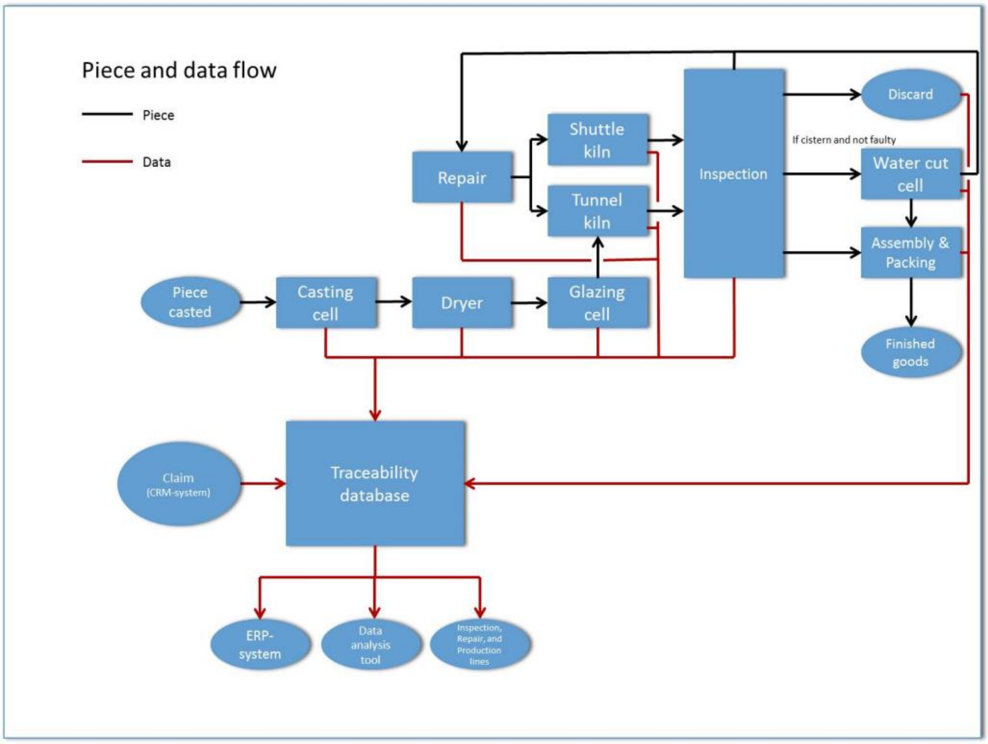

Figure 48 - Piece and data flow for the traceability system

8.1.9 Summary of the machines needed

The piece markers need to be placed in each and every casting cell, which leads us to to 23 piece markers. All racks used in the production system needs to be marked, which sums up to approximately 580 permanent bar code labels. All kiln cars will also need be marked, there is approximately 570 kiln cars that needs to be equipped with permanent ceramic bar code labels. All of the glazing cells need to be equipped with a fixed piece reader with DPM-support in order to read the Data Matrix on the piece, this sums up to 22 readers. All of the inspection stations, as well as the repair stations need to be equipped with manual piece readers with DPM-support in order to conduct their operation in a satisfying way, this sum up to 20 readers. A manual rack reader connected to a PDA should be added to every forklift, this means 7 readers. The kiln cars will need to be read every time they enter a glazing cell or a tunnel kiln, this sum up to a total of 16 fixed readers. A summary of each type of equipment needed can be found in *Table 6*.

Table 6 – Type of equipment needed for the AIDC-system

Operation	Equipment	Total amount	Remark
Piece marking	Electro mechanical dot peening	23	Total number of marking machines
Rack marking	Permanent bar code labels	Approx. 580	Total amount of markings
Kiln car marking	Permanent ceramic bar code labels	Approx. 570	Total amount of markings
Fix piece reader	Image-based reader with DPM-support	22	
Manual piece reader	Image-based reader with DPM-support	13	
Manual piece reader	PDA with image-based reader with DPM support	4	
Manual rack reader	Hand-held laser reader with PDA	7	
Fixed kiln car reader	Fixed mount laser reader	16	

8.2 Cost-benefit

This subchapter will explore if it is cost-beneficial to implement a traceability system in Ifö's production system. In order to attain structure on the different aspects, Boardman's approach will be used. Step 6 that deals with discounts for time to find present values will however not be carried out, since only the payback-period is of interest at the company.

8.2.1 Initial investment cost

The initial investment cost is based on a quotation from an AIDC supplier. The number of reading and marking equipment is based on the proposal mentioned in subchapter *8.1.9 Summary of the machines* needed.

The IT-system cost has been estimated from previous quotation on a similar IT-system and an estimation on the time required to write the code for such a system. The cost of bar code labels has been estimated by internet searches, see *Table 7*.

Table 7 – The initial investment and how the costs have been calculated

Operation	Equipment	Measurement indicator	Quantitative impact	Monetize
Piece marking	Electro mechanical dot peen	Cost per unit	Number of casting cells	Supplier quotation
Rack marking	Permanent bar code labels	Cost per label	Number of racks	Cost estimation
Kiln car marking	Permanent ceramic bar code labels	Cost per label	Number of kiln cars	Cost estimation
Fixed mount automatic piece reading	Fixed image-based reader with DPM support	Cost per reader	Number of glazing cells	Supplier quotation
Manual piece reading	Hand held image-based reader with DPM support	Cost per reader	Number of repair-, inspection- and manual assembly stations	Supplier quotation
	PDA with image-based reader with DPM support	Cost per PDA	Number of production lines	Online quotation
Manual rack reading	Hand-held PDA laser reader	Cost per reader	Number of forklifts in the production lines	Cost estimation based on previous purchases
Fixed mount automatic kiln car reading	Fixed mount laser reader	Cost per reader	Number of kilns and glazing cells	Cost estimation based on previous purchases
Inspection	Touchscreen	Cost per touchscreen	Number of inspection stations	Online quotation
Data storage	IT-system	Cost of IT-system and integration	Data storage and transfer capacity	Cost estimation based on previous quotation

8.2.2 Whose benefits and costs counts?

An implementation of a traceability system will affect the operations at Ifö in many aspects. The personnel in the factory, as well as stakeholders, will be affected in different ways, and must be taken into consideration in this analysis.

- Operators at the production lines
- Inspectors
- Production supervisors
- Production schedulers
- Re-firing
- Claims handling

With an introduction of a traceability system the operators, production supervisors, and the production supervisors will spend less time on the production reporting. The re-firing will also be affected in terms of fewer pieces in need of re-firing and the possibility of optimization of the re-firing. The time spent today on filing an inspection report will be allocated to more time inspecting every individual piece, this in addition to better understanding of the processes will lead to less claims overall.

8.2.3 Portfolio of alternate projects

Three alternatives will be taken into consideration in the investment appraisal:

- Extensive implementation of a traceability system with the end goal to achieve total traceability
- Alternative option with the use of labels
- Alternative option with partial implementation of a traceability system

The first alternative would lead to an implementation of a traceability system, where each and every piece's path through the production can be gathered, and where the traceability easily can be extended to involve more aspects. The second alternative would mean an implementation of the same amount of traceability as in the first alternative but instead of DPM-markings on the piece, labels are used. The last alternative is an partial implementation of a traceability system, the pieces are marked according to the first alternative, but only read in the inspection.

8.2.4 How the cost savings have been calculated for the main proposal

For the operators there are two aspects that will be covered in the cost-benefit. The time put on manual production reporting, should be carried out automatically by the traceability system in the future. This leads to that all of the time spent on production reporting can be allocated to other activities, including corrective actions by the production supervisors and production schedulers. The savings can be measured in operator cost savings per year. Currently, the inventory of pieces in need of re-fire is stock-taken continuously by an operator. This time can also be allocated to other activities. The time allocated to these activities has been estimated through observations, interviews, and a survey, the survey can be found in *Appendix 3*. The quantitative impact has been calculated through these estimations in hours per year. With the costs per hour for the different employees available the annual cost savings can be calculated.

The inspectors will allocate a lot less time to inspection reporting, thus the time savings can be spent on other activities that adds more value to the company. The time allocated to typing in the inspection report was estimated through time measurements at different inspection stations, and different inspectors. The time measurements where divided into time to type in an approved piece and time to type in a piece in need of re-fire. The time to type in a piece that was discarded was assumed to be the same as for a piece in need of re-fire, the number of measurements where too few during the timekeeping and the amount of information that the inspector needs to type in is identical to if the piece was in need of re-firing. With number of pieces inspected last year available in the ERP-system, the estimated total time spent on filing the inspection reports was calculated. The inspector cost per hour was available, and with this the annual inspector cost savings were calculated.

Better traceability will lead to a decrease in the re-firing operation, due to faster response time on defects at the production lines, and optimization of mainly the re-firing process. A standard amount of what the re-firing operation costs each year was available at the company, and the senior management of the factory estimated a percentage decrease.

The claims will also decrease as a result of better traceability, and more time spent on inspection of each and every piece. Only claims for the Ifö brand will be included in the cost-benefit. The total claim cost for each product type was attained from the service unit. Overhead costs were added to the total claims cost, this includes costs for service technicians, external plumbers etc. An estimation was made by the senior management at the factory regarding a decrease in number of annual claims.

Table 8 – Cost savings for the ideal solution and how they have been calculated

Affected parties	Potential aspects	Measurement indicator	Annual quantitative impact	Monetize
Operators in the production	Time savings due to less manual production reporting	Annual operator cost savings	Average time spent per production line per day on production reporting times number of working days per year	Operator cost/hour
	Time savings due to no need of additional stock-takings	Annual operator cost savings	Average time spent by single operator on stock-takings of pieces in need of re-firing per year	Operator cost/hour
Inspectors	Time savings due to less time spent on filing inspection reports	Annual inspector cost savings	Average time spent per production type divided into accepted and re-firing times number of products inspected	Inspector cost/hour
Production supervisors	Time savings due to less manual production reporting	Annual production supervisor cost savings	Average time spent on production reporting per day times number of working days per year	Production supervisor cost/hour
	Time savings due to less time spent on corrective actions	Annual production supervisor cost savings	Average time spent on corrective actions into the ERP-system per day times number of working days per year	Production supervisor cost/hour
Production schedulers	Time savings due to less time spent on corrective actions	Annual production scheduler cost savings	Average time spent on corrective actions into the ERP-system per day times number of working days per year	Production scheduler cost/hour
Re-firing	Decrease in the re-firing operation, due to faster response time and optimization of the production processes (incl. the re-firing operation)	Cost savings for percentage decrease in number re-fired pieces	Estimated decrease in number of re-fired pieces	Standard amount for percentual decrease in number of re-fired pieces
Claims handling	Decrease in number of claims, due to more thorough inspection, faster response time, and optimization of the production processes	Cost savings for percentage decrease in number of claims	Estimated decrease in number of claims	Total claim cost per product type and additional overhead costs

8.2.5 Investment appraisal

The method chosen for calculating whether the investment is profitable, and during which time period, is the payback method. The payback method was chosen because it gives an easy-to-understand idea if the investment is profitable or not. According to Yard (1987, cited by Persson & Nilsson, 1999) this method is the most used in the Swedish manufacturing industry and is also the only method used at Ifö.

With Table 6, 7, and 8, and the monetary values associated with them, which are not disclosed in this report, a payback-period could be calculated for the main proposal:

PB = 1.35 years

The payback period of 1.35 is within the period that is deemed profitable by Ifö and therefore the proposal is eligible for investment.

8.2.6 Sensitivity analysis

A sensitivity analysis was made to ensure the viability of the investment in the proposed traceability system.

Low

Here, the authors assume that the time saved for the operators, production supervisors, production schedulers and unwarranted stock-counts could not be quantified in monetary terms. Still, the time saved for the inspectors should equal a full time shift-working inspector. Therefore, only the time saved for the inspection was monetized.

In regards to the reduction of re-firing and claims, the authors calculated with half the reduction compared to the main proposal.

With the exception of those aspects, the same numbers and method of calculation was used as in the main proposal. This gave a payback time of:
PB = 2.66 years

This payback time is still in line with Ifö's investment policy.

High

In this sensitivity analysis, the authors estimated the reduction of re-fire and claims will be 50% greater than for the main proposal. The cost of equipment, labels and IT-system was discounted with ten percent compared to the main proposal. This gave a payback-period of:
PB = 0.90 years

This payback time is less than a year, giving a great investment.

8.2.6.1 Alternative option with the use of labels

In the chapter *5 Experiments*, conclusions were drawn that the wet slide ceramic bar code labels provided excellent results, albeit hard to integrate in the automated production system. Therefore, the authors did a cost-benefit analysis on the use of manually applied wet slide labels.

The annual savings is the same as for the main proposal in subchapter 8.2.5 Investment appraisal. The initial investment cost is about 1/3 of the main proposal. However, the annual cost of labels is 135 % of the annual savings and the additional labor costs associated with the manual application of the labels is 65 % of the annual savings.

It is easy to realize that the annual savings are less than the annual cost of the labels. Therefore, even if automated labeling equipment was used, the use of wet slide ceramic labels is not cost-beneficial.

8.2.6.2 Alternative option with partial implementation of a traceability system

In this alternative, only the marking of the pieces in the casting cell and the subsequent reading of them in the inspection area were analyzed.

This means that there is no more traceability than the current situation throughout the processes in the production line, the information flow will be better though since each piece number will include all defects for better follow-ups. It also means that there will be no need for readers or markings at the dryers, glazing cells or kilns. The IT-system will also be less complicated since it only has to store data on when the piece is made, when it was inspected and if it is approved, needs re-fire or is discarded.
The authors estimate that the reduction in re-firing will be 25% of that of the main proposal due to no improved traceability in the re-firing area. The decrease in claims was estimated to 75% of the main proposal due to less traceability in the processes. The time spent on filing of the inspection report will almost the same as the current situation because the inspector would still have to type in the casting cell, glazing cell and the kiln. This alternative will give a payback-period of:
PB = 1.67 years

9 Conclusion

In this chapter the authors summarize the thesis, analyze and draw conclusions regarding the findings, proposal and investment demand.

It can be concluded that Ifö Sanitär in Bromölla has a prominent position in the sanitary ware industry, because of their investments in a state of the art high pressure casting technology a decade ago. During the course of the decade the factory has become the most productive one in the Sanitec Group, and in order to keep their position, and excel knowledge-wise, the ability to trace defects must increase. The need for traceability in the sanitary ware industry is not related to legislation or other direct requirements. It is however a competitive advantage to be able to track and trace the product as this provides both time savings in the production, as well as good basis for process improvements.

During the course of the project a possible solution has been developed for the factory's specific needs. This was acquired by a mapping of the production system, the mapping and the frame of reference of traceability led to a specification of requirements for the traceability system, including the traceability method. This specification was used in order to invite suppliers of these types of systems.

The solution includes a direct part marking on all of the main product types that is produced in Bromölla, with an individual serial number. All products need to be individually marked since the path through the production system can differ significantly for identical products. The ability to conduct follow-ups on defects and performance of different parts of the production system will not improve significantly in comparison the current state if only a partial traceability solution is chosen.

A stand-alone IT-solution has been chosen for this traceability system, since integration with the current ERP-system would be insufficient for a number of reasons. One of the major issues is that when incorrect information is filed into the ERP-system it becomes cumbersome to deal with, and both the incorrect information and the corrective actions because of them, affects the whole production scheduling process, as well as the performance of the factory. The solution is a stand-alone system that is mainly used by the factory personnel, where information that is needed in the ERP-system is transferred every day automatically, and where the responsible person for different parts of the production system are able to make corrective actions before it is sent to the ERP-system, and becomes cumbersome to deal with.

Readers will conduct the registration of all of the products' paths through the production system, either the DPM-marking on the piece is read or a marking on the carrier of the piece. The reasoning behind this solution is that the products will be marked in different locations depending on product type, and a general reading location for all product types will be hard to identify. Instead the carriers are marked and read, and a connection between the product's individual number and the carrier's individual number will be made in the IT-system.

A system is never better than the information that it is fed with. The input will also need to improve in order to achieve a successful implementation. The information currently supplied by the inspection to the ERP-system for the purpose of traceability is lacking. All defects are not included, since the filing of this information is time-consuming, furthermore all traceability information is supplied to the system by a single operator for each and every product. The inspection will be optimized significantly if the information is supplied automatically when the product passes through the production process, and the only information the inspector supplies is all of the faulty reasons and the faulty locations. The input from claims must also be improved significantly, since the information supplied to the production lines must be based on facts and not estimations from the service technicians. Instead the currently used CRM-system should supply the traceability system with information regarding the claim every time a claim case is closed.

Another issue that needed to be addressed was if it is cost-beneficial to invest in a traceability system if there is no legal requirement on the company to do so. It was concluded that the time savings, mainly due to less manual production reporting and filing of inspection reports was substantial. These time savings in addition to estimated decreases both in re-firing of products and claim cases would lead to a payback-period of 1.35 years, which is well under the company's required payback-period.

10 Implementation plan

This chapter is an implementation guide for Ifö which can be used to enable the successful implementation of a traceability system.

The implementation of the traceability system should be conducted stepwise. For Ifö's specific conditions, it is wise that a pilot study is performed in order to analyze both the AIDC requirements in live operation as well as the database and IT connectivity needs. This will allow for a learning curve so that the major system development and implementation runs as smoothly as possible. For the pilot study, the authors recommend that the standard washbasin line is to be used. This is because of its relative simplicity and high yield.

For the design of the pilot system, the subchapters *6.7 Appropriate design of a traceability system at Ifö Sanitär Bromölla* and *7.2 Specification of requirements for the traceability system* should be studied.

In this stage is important to create a project team that develops the leads the pilot project. The authors recommend the following internal personnel to be part of the project group:

- One project manager (full time)
- One production supervisor
- One process support
- One production scheduler
- One process support of the inspection
- One IT and ERP integration expert
- One quality control
- One technical advisor

Further, it would be wise to include personnel from finance and purchasing.

When the marking method, reader technology and traceability needs has been established, a Request For Proposal (RFP) should be developed with detailed a specification containing the specification of requirements listed in *Appendix* 1.

An internal plan for implementation of the pilot study should be designed. The following activities should be considered as suggested by Pearce & Bushnell (2010):

- A complete project schedule with timetables and milestones
- The acquisition and scheduling of human resources
    - Internal
    - Technology provider
    - Third parties, e.g. consultants
- Acquisition and scheduling of facility modifications
    - Modify the casting cell to accommodate a marking machine
    - Modify the glazing cell to accommodate for a fixed mount reader
    - Modify the inspection table to accommodate reader and new inspection computer/interface
- Acquisition and scheduling of equipment
    - Installation of marking machines and fixed mount readers
    - Installation of new inspection computers
- Acquisition and scheduling of software
    - Applications. E.g. inspection interface
    - Communication. E.g. WiFi, Ethernet, RS-232 etc.
    - Off the shelf software or special built
    - Database management system
    - Operational data
- Acquisition and scheduling of training program
    - Documentation: user manuals, standardized procedures, technical manuals etc.
    - Schedule personnel for training and education
    - Evaluate training program and attendees
- Design system test procedures
    - Hardware, software, database, and operational inputs
    - Define system response to input
    - System outputs
    - Acceptance criteria
- Verification of Database
    - Piece number
    - Product code

- Location code
- Connection with carriers
- Stock levels
- Classification (1st fire, re-fire, discarded etc.)
- Defect type and location
- Others as they apply (employee number, shift etc.)

When the pilot is up and running, it is vital to analyze and evaluate what needs to be improved and what data is lacking. This should be thoroughly documented and become the baseline for the specification of the factory wide system.

11 Additional work

In this chapter additional work in accordance with an introduction of a traceability system is discussed.

The requirements of the IT-system have only been functionally specified by the authors. This aspect needs to be specified extensively in order to satisfy the needs of the whole production system. This would most preferably be conducted during a possible pilot of the system on a single, or part of a, production line.

In order to secure a good transition to a new traceability system, representatives from all of the departments should be included in the development of the system. If all of the personnel feel that they have been included in the development process, the transition will be much smoother, and teething problems can be dealt with at an early stage.

If extensive tracking of pieces before they are transported to the finished goods warehouse should be included in the traceability system, a mapping of the different storage locations needs to be conducted and precision specified.

Additional work should also be carried out regarding the dot peen marker. Optimizations on specific products and the most suitable marking location on different product types needs to be identified.

11.1 Possibilities with a traceability system

The introduction of a traceability system will be a gate-opener to several new business improvements. Some of the most obvious ones will be covered in this subchapter.

The documentation of process changes could and should be further improved. The introduction of a well-functioning traceability system will be an incentive in this process. If certain pieces can be traced to specific timeframes, a database containing process changes can be used in order to analyze what effects a certain change provokes.

To further improve the documentation of process improvements due to defects in general is also of utmost importance with a traceability system in use. When a root-cause for a certain defect has been identified and solved, it should be documented with information containing what process changes have been carried out to solve the defect. It would improve the handling of claims significantly if the quality control could cross-reference an issue immediately instead of taking the issue to the production supervisors. With a piece identification number at hand, the quality control could cross-reference the timeframe with solved issues for the highlighted product.

The application that is used today to supply the quality control and the service unit with claim statistics is simply, not good enough. A CRM-system is used to document all claims, but there are however no statistics available to either the service unit or the quality control. There are ongoing discussions that the CRM-system should be incorporated in the ERP-system, but when this can be achieved is uncertain. Another solution might be that each time a case is closed in the CRM-system, the piece id-number, defect type, and defect location is supplied to the traceability system. If the piece is not equipped with an id-number, it can be handled in the regular fashion. The introduction of a traceability system should however be an incentive for the service unit to improve their systems in order for them to communicate with the traceability system.

The introduction of a traceability system can also be seen as a starting point for extensive traceability of the whole supply chain. The suppliers could be included with order numbers and dates, as well as customers with documentation of which pieces they have received from Ifö, not to mention the ability to track pieces at the transport undertakings.

12 Discussion

In the chapter the authors analyze the value of this thesis and hos the traceability system will affect operations.

12.1 The value of this thesis

For a majority of the project, the collection of data was centered on observations of different parts of the production system. These observations were then validated through interviews with operators, process-supports, as well as with production supervisors, the quality control etc. The purpose of these interviews were to make sure that the information gathered by the authors coincided with reality, and in addition to this explore new angles of the production system that also would be affected by a traceability system.

This thesis has to a large extent been focused on qualitative data in order to understand, and fit a traceability system, into the production system. The data gathered both from observations, and interviews have been presented for the process-supports, production supervisors, and the senior management of the factory, in order to confirm its reliability. Information regarding claim data have been discussed both with quality control personnel, as well as personnel from the service unit in order for the authors to not draw incorrect conclusions.

The project was carried out by the authors that had little to no none knowledge beforehand of the sanitary ware industry and the production process. In order to avoid biases the information gathered from personnel on the factory floor was treated with the same interest as information from the senior management. The main notion was to consult the person that was closest to the information sought by the authors.

The project has been conducted in close collaboration with Ifö's factory in Bromölla. The solution proposed by the authors cannot be transferred into another production system if the system is not as automated as the one in Bromölla. The approach used by the authors can however be applied on any production system.

In subchapter *3.5 Traceability method* several marking methods are discussed, these methods have been identified by internet searches. It is possible that there are relevant marking methods available that have not been identified by the authors. The methods discussed in this subchapter cover the type of marking methods that the authors deemed relevant to the marking of ceramic materials.

12.2 How the system will affect the operations

The introduction of an automated traceability system is meant to improve all functions from the raw material handling to the end-customer. The different functions will make use of the system in different ways.

12.2.1 Operators in the production lines

The operators work tasks will change with the introduction of a traceability system. The current situation requires that a lot of reporting is carried out manually and the time it takes depends on the operator's experience. It is however not value-adding to the process to spend time on compiling number of pieces produced every day. This time could and should be spent on making sure that the production process functions properly and to make improvements on the process.

With the introduction of a traceability system, the need for reports issued by operators regarding number of casted and glazed pieces will decrease. Ideally there will be no need for the operators to once a day read number of casted and glazed pieces from the PLC's, this should be handled automatically by the traceability system. A faulty piece should be recorded in the traceability system by the operators immediately when it is identified. If many faulty pieces are inspected an automatic alarm could be sent to the operators, ensuring that they take action against these defects as fast as possible.

12.2.2 Inspectors

There would be major changes in the inspection with an introduction of a new traceability system. In order to gather all information that is needed in order to make good judgments regarding the processes, the inspection reporting needs to go through changes as well. The inspector should not be able to directly affect the performance of the company with a simple typing. The information should be stored in the traceability database and then transferred into the ERP-system by the production supervisor, the person that is directly affected by incorrect data. With this introduction the inspectors will be focused on what they are meant to do, inspect the piece thoroughly and supply the production system with defect types and defect locations.

12.2.3 Production line management

There should not be a need to report the number of pieces produced when a well-functioning traceability system has been integrated in the production system. The data will also be more reliable than it is today with manual reports. The role of a production supervisor is to work with quality and process improvements in the production lines, not to file reports in order to make follow-ups.

The production supervisor will be able to make judgments on process and quality improvements with relevant and reliable data from the traceability system. With a traceability system the follow-ups will be available in real time, which means that the production supervisors can react much faster to fluctuations in quality measures.

12.2.4 Production schedulers

As it is today the production schedulers can only take number of casted pieces and number of inspected pieces in consideration when they plan the production according to the master plan. Since major discrepancies is a factor for the internal inventory stock the scheduling becomes problematic, and the experience of the schedulers plays a major role in order to plan the production in a satisfying way.

With a satisfying implementation of a traceability system the production schedulers will be able to trust the number of work in process, and plan according to what actually is in the system. The production schedulers would work a lot less in the dark, and optimizations of the WIP stocks could commence.

12.2.5 Quality control

The information available to the quality control today regarding claims is poor, and a lot could be gained with a traceability system. This is however dependent on the CRM-system's compatibility with the existing systems and the traceability system. The information that is supplied to the quality control today is not based on facts and a transition to the CRM-system is much needed. There is however no need to incorporate the CRM-system with the ERP-system from a traceability system perspective. In the future the

CRM-system should include that the service technician needs provide the id-number for the piece, and every time an id-number is supplied and the case is closed the relevant information is transferred to the traceability system. The information available to the quality control with these changes will be very precise and the production lines will be fed with relevant information during a specific timeframe, which will further improve the ability to make process improvements. A product can be produced at several plants simultaneously, and there is no easy way to know if a product that is produced elsewhere to, has been produced in Bromölla or not, if the mold number is not supplied. With the support of a traceability system it will be easy to rule out products that have been produced elsewhere.

The internal audits issued after the inspection can be improved considerably if all defects are recorded. The planning of which products that is in need of audits would be based on facts to a larger extent than it is today, since not all defects are reported and since the claim information is poor.

12.2.6 Service unit

The service unit would gain a lot with a well-functioning traceability system, especially during recalls where a very specific amount of pieces could be highlighted at the wholesalers. The age would be instantly determined for a piece and the liability for it easily determined. The ability for the service unit to optimize the issuing of recalls on defect products would also improve significantly, since the precision would increase tremendously. All products that are involved in a claim should be discarded by the service technicians in order to make sure that they do not find their way to the market again. With an id-number on every piece it would be impossible for a piece to be in a warranty claim more than once.

If trusted service technicians had access to parts of the traceability system, i.e. known issues on specific models, the ability to assess the defect fast would increase. The filing of claim information by the service technician would not change dramatically, the piece id-number would need to be supplied in addition to what is supplied today. In the future the filing could be simplified considerably with an introduction of a smartphone application that reads the piece id-number and supplies all information regarding product type, brand etc. Only the defect type, defect location, and pictures of the defect would need to be supplied by the service technician on site.

13 Contribution to the academia

This thesis is strongly based on the conditions at Ifö Sanitär. With that in mind, several of the findings in this report can still be used as a reference for sanitary ware production and similar types of manufacturing.

Firstly, this thesis outlines to benefits with traceability in an industry that does not have legislation or other enforcing requirements. Further, the benefits with a real-time traceability system enable manufacturers to improve their production control as well as their quality. In the literature, this often brought to attention for the automotive and process industry. However, the authors concluded that these benefits had not been clearly outlined for the ceramics industry.

Secondly, the authors have not found any support in the literature related to the use of automated marking and tracking of unfired ceramics throughout the entire production process. This thesis provides researchers and manufacturers with detailed experimental analysis of what works, which benefits each technology has, and which technologies that are not worth pursuing.

The authors encourage further research on both the benefits with traceability in sanitary ware production and the marking of unfired ceramics since there are little to no literature on the subjects.

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Appendix 1

Specification of requirements for the traceability system

Functional requirements

- Physical process fully or to the largest extent, automated
- The marking should be placed on the piece after it is casted and before it is dried
- The flow of goods cannot stop if the marking is not read
- If the marking cannot be automatically read there must be a redundancy system available to the operator
- The system needs to alert the operator when a piece cannot be read
- Control points should be placed adjacent to each process-step
- The permanent marking should be placed at a location where it can be read by an industrial robot or so that the robot can place the piece so that the marking can be read
- A control point that is not in the vicinity of an industrial robot needs to be registered into the system in another way.

System requirements

- The database should contain information for each individual piece
- Each control point in the production solely registers the marking, the time, and possible connection. Except for the casting where the product number and mold number also is supplied
- The inspection control point registers the time, faulty reason, faulty location and if the piece have been approved, discarded or if it needs to be re-fired
- The information should contain information on when each step in the process begins and ends
- The piece's identification number should be able to connect to another identification number
- Transport carriers should have identification numbers
- The transport carriers' identification numbers should be connectable, and act as parents to the pieces' identification numbers
- When a transport carrier passes through control points the information should be connected to the pieces' identification numbers
- The data should be stored for five years
- The operator must be able to make changes in the system
    - Discard a piece (with faulty reason)

    - Manually assign a piece to a cell
    - Manually correct a faulty piece reading
- When five years have passed, the identification number only refers you to the product number and the date for assembly
- Once a day the system should export number of casted and glazed pieces from each cell to the business enterprise system
- The database should be compatible with analysis tools
- The system should handle a high amount of information each day from several control points simultaneously
- Authority should dictate what a person can receive from, or send to, the system

Technical requirements for AIDC

- The data carrier (bar code, RFID, or other) should be applied on moist green ware by the use of automated equipment
- The data carrier should be readable by data capture technologies (readers) throughout the process and on the aftermarket
- The data carrier should provide human readable information as a backup
- Shrinkage of the material during drying (3,5 %) and firing (10 %) should be accounted for
- The data carrier should withstand temperatures of up to 1205°C for 16 hours
- The data carrier should be permanent
- The reader should have a read rate of >99 % and a time-to-read of less than one second with the data carrier
- The readers should consist of both fixed and hand-held readers
- The reader should be able to communicate with a PLC, work independent, or via a trigger (sensor or manual)
- The reader should be able to communicate seamlessly with the traceability system. Output data should at least include time and date, reader location, and the information in the data carrier

Appendix 2

1D bar codes

There are two fundamental ways of encoding information in a one-dimensional bar code, delta codes and binary codes (*Figure 49*). In the former way, the interval is subdivided into modules and is assigned 1's and 0's to each module. Modules with 1's are painted and form the bars, while modules with 0's represent spaces.
In the latter scheme, the binary code, each bit is assigned to a bar or a space and makes that element wide if the bit is 1 and narrow if the bit is 0. The term width code would be more suitable, but since only two widths are used, binary code is the more commonly used name (Pavlidis, et al., 1990).

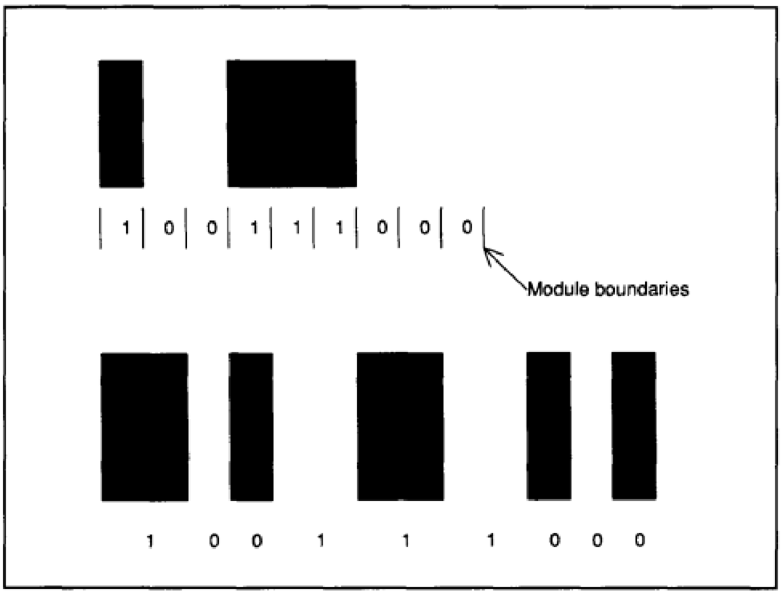

Figure 49 - The delta code is represented above and the binary code below. (Pavlidis, Swartz & Wand, 1990)

1D bar code types

Universal Product Code (UPC)

This is a delta code that has been used in American supermarkets since the mid 1970's and is the most commonly used code symbology in the retail industry (Pavlidis, et al., 1990). EAN or European numbering system is the European version of UPC with an added digit, usually representing a country

code.
In the UPC-A, each symbol encodes 12 digits. UPC-A consist of 11 data digits and on check digit. UPC can only represent 20 characters (10 each of 2 different parities) and digits 0-9. The symbol contains a left guard pattern, and the first digit is a number system digit that usually represents the industry type (such as 0 for grocery, 3 for pharmaceutical, etc.). The following five digits are a manufacturer's code, a center guard patterns of five modules and the next five digits are used as an item identification number. Lastly there is a check digit and a right guard pattern, see (Pavlidis, et al., 1990). There are several versions of UPC but the A version is the most widely used.

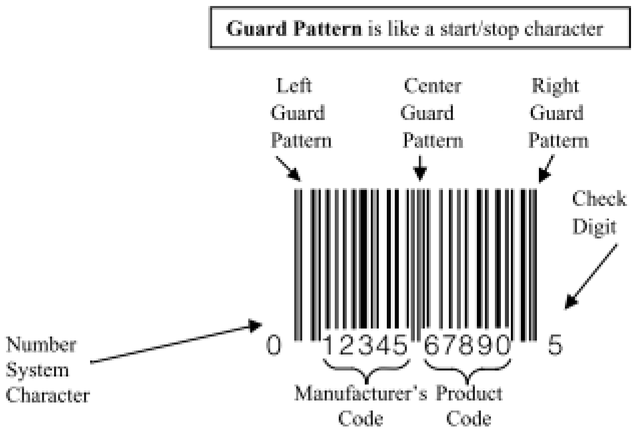

Figure 50 - Structure of the Universal Product Code (Muller, M 2003 pp. 99)

Code 39

This symbology is a binary code, introduced in 1975, and is the most widely used bar code in nonretail applications. Code 39 is sometimes referred to as "3 of 9 Code" because three of the nine elements (bars or spaces) making up a Code 39 character are wide (binary value 1) and the other six are narrow (binary value 0) (Muller, 2003, pp. 89-113). The total number of code words that it can generate is the number of ways three items can be chosen out of nine, i.e. 84. It has code words for the 10 digits, the 26 letters, and eight special symbols (hyphen (-), period (.), space, *, $, /, + and %) (Pavlidis, et al., 1990).

Code 128

This symbology is a delta code, introduced in 1981, has 11 modules and three pairs of bars and spaces (Pavlidis, et al., 1990). This symbology has many desirable features, such as using three start codes to allow the encoding of all 128 ASCII characters. Therefore, the entire alphabet in both upper and lowercase, all ten numeric and all special characters can be used (Muller, 2003).

Interleaved 2 of 5

Table 9 – Examples 1D bar codes

UPC-A Encoded information: 123456789	0 01234 56789 5
EAN-13 Encoded information: 123456789	0 001234 567895
Code 39 Encoded information: CODE-39	*CODE-39*
Code 128 Encoded information: Code 128	Code 128

Interleaved 2 of 5 Encoded information: 123456789	1234567895

2D bar code symbologies

Table 10 - 2D bar code symbologies and their storage capacity, adapted from A. grover et al.

2D Bar Code Symbology	Data carrying capacity (max number of characters)			
	Numeric	Alphanumeric	ASCII/binary/bytes	Japanese Kanji characters
PDF 417	2710	1850	1108	
QR Code	7089	4296	2953	1817
Data Matrix	3116	2335		
Aztec Code	3832	3067	1914	

Alternative methods

Laser etching is similar to laser coloring, but the heat applied to the substrate is higher, causing the substrate surface to melt, see *Figure 51*. It is only applicable to certain metals, metallic coasted surfaces and some plastics. The advantage of this method, compared to laser coloring, is increased marking speed since the process depth is less than required to color metallic substrates. The disadvantage of this technique is that it can cause cracks in the molten metal during the cooling which can propagate into the underlying surface material (National Aeronautics and Space

Administration, 2008a).

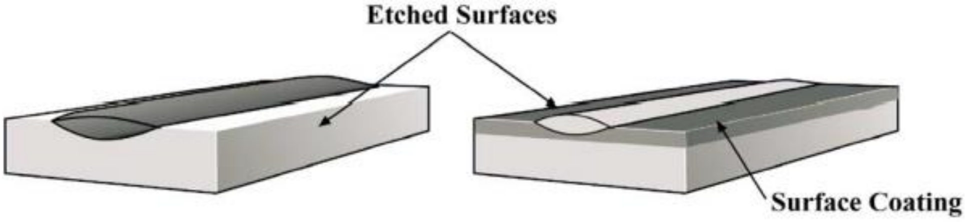

Figure 51 - The left figure displays laser etching applied directly to the surface. To the right, laser etching is applied to a surface coating (National Aeronautics and Space Administration, 2008a).

Laser coloring is a process used to discolor metallic materials without burning, melting or vaporizing the material, see *Figure 52*. This type of laser marking produces a high quality and contrast marking that does not disrupt the surface. This marking method does only work on some metallic substrates and can cause adverse effects on materials that have previously been heat treated, it can also reduce corrosion resistant properties of stainless steel alloys (National Aeronautics and Space Administration, 2008a).

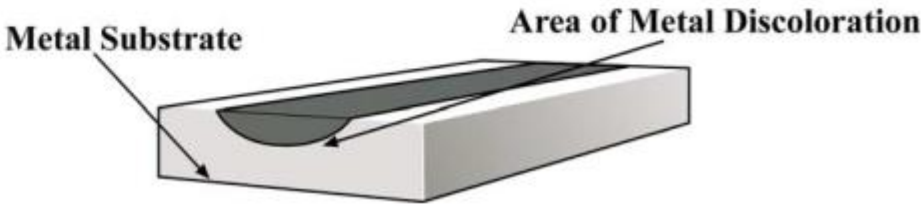

Figure 52 - Marking applied to surface using the laser coloration process (National Aeronautics and Space Administration, 2008a).

Identification Keys

Global Trade Item Number (GTIN)

The GTIN is the foundation of the GS1 System (formerly the European Article Number (EAN)/Universal product Code (UPC)) for uniquely identifying trade items, which includes both products and services that are sold, delivered, and invoiced at any point in the supply chain. GS1 is an international not-for-profit association dedicated to the design and implementation of global standards and solutions to improve the efficiency and visibility of supply and demand chains globally. The GS1 system of standards is the most widely used supply chain standards system in the world (GS1, 2013)

GTINs provide unique identification numbers worldwide, and can be encoded into various types of bar codes and Electronic Product Codes (EPC) which are programmed into Radio Frequency Identification (RFID) tags (GS1, 2006). GTINs are 8 digits, 12 digits, 13 digits, or 14 digits in length.

- GTIN-8 is used in EAN-8 bar codes
- GTIN-12 is used in UPC-A and UPC-E bar codes
- GTIN-13 is used in EAN-13 bar codes
- GTIN-14 is used in ITF-14, GS1-128 (Code 128), Reduced Space Symbols, and Data Matrix bar codes, plus EPCs

Table 11 - Example of unique identification at various levels and with various bar codes (GS1, 2006)

Descrip.	Item	Level	Bar Code	Encoded GTIN	GTIN in database
Product A	1 Unit	Consumer	UPC-A	614141000012	00614141000012
Product A	96 Units	Case	ITF-14	00614141000029	00614141000029
Product B	1 Unit	Consumer	UPC-A	614141000777	00614141000777
Product B	6 Pack	Consumer	UPC-A	614141000883	00614141000883
Product B	12 Pack	Consumer	UPC-A	614141000999	00614141000999
Product B	2x12 Pack	Case	GS1-128	10614141000996	10614141000996
Product B	4x12 Pack	Case	GS1-128	30614141000990	30614141000990
Product B	8x12 Pack	Case	ITF-14	50614141000994	50614141000994

The GTIN identifies an item uniquely, and every variation of an item is allocated a single reference number that is globally unique. The GTIN numbering structure is only a key to a database, hence, it does not contain any meaningful information in itself. One of the key benefits with GTIN is that it can be encoded in many automatic data capture technologies, such as bar code or EPC used in RFID tags. The machine reading allows for the information flow to be linked to a physical flow of items through the supply chain (GS1, 2006).

13.1.1 Electronic Data Interchange (EDI)

EDI is defined by (Becker, 1990) as "electronic data exchange of structured and standardized business data between computers". The United Stated Department of Commerce further defines EDI as "the processing of received messages by computer only, and human intervention in the processing of received messages is typically intended only for error conditions, for quality review, and for special situations” (U.S. Department of Commerce/National Institute of Standards and Technology, 1996).

Through EDI the contents of documents, such as purchasing orders, claims and invoices can be structured into electronic messages. These messages are generated by computer applications which initiate the electronic transmission to the receiver where corresponding applications receive the messages and distribute them throughout the in-house It-system. This requires that the sender and receiver speak the same “language”. Therefore, a number of standards have been set (Becker, 1990):

- UN/EDIFACT: the only international standard, which is mainly used outside of North America
- ANSI ASC X12 (X12), which is mainly in North America
- TRADACOMS standard used mainly in UK retail industry
- ODETTE standard used within the European automotive industry

Appendix 3

Pictures and figures related to the production system

Figure 53 - Racks for the standard washbasins line

Figure 54 - Kiln car on a rail, leading it to a tunnel kiln

Figure 55 – Chain of command in the production

Description of the production lines

The VC-lines supplies two tunnel kilns, 19 and 20, with pieces. All pieces produced in the VC-lines are inspected in the inspection area mentioned in the *Production line for standard washbasins* subchapter. A piece that needs to be re-fired is sent to one of two repair-locations. One of the locations sends the repaired pieces for another run through tunnel kiln 19, the other repair location has two kilns that are dedicated to re-fired pieces, shuttle kiln 4 and 5.

The FFC-lines supplies tunnel kiln 21 with pieces. The pieces produced in the FFC-lines are however inspected in a specific inspection area that only handles FFC-pieces. A piece that needs to be re-fired is sent to a specific repair-location for FFC-products. This repair-location has a dedicated kiln as well, shuttle kiln 3.

There are five electric kilns available for pieces that need to be re-fired. These are however rarely used since the firing of pieces is expensive and they are cumbersome to load and unload.

If the small non-automated production line with plaster molds is not included, there are four production lines in the Bromölla factory. Two manages VC-slip and two FFC-slip.

Figure 56 - Ifö Sign WC unit short model 6832

The casting of bowls consists of 10 casting cells, each press in every cell is of a one-piece type. There is however 2 molds in each cell, which means that the line can cast 20 bowls simultaneously. The casting of cisterns is carried out by a carousel press, which can cast 12 cisterns simultaneously. The bowls and the cisterns are dried in 10 dedicated dryers. The glazing of the pieces is carried out in 8 glazing cells where 6 are dedicated to bowls and 2 to cisterns. When finished the pieces are placed on a kiln car and transported to the kiln waiting line by an automatic forklift, AGV.

The high volume production line produces vanity tops and sinks for the global furniture retailer. It consists of 6 casting cells, and each press in every cell is of a one-piece type. There can however be up to 4 molds in press, which means that the production line can cast 24 pieces simultaneously. There are 6 dryers that are dedicated to the line and 3 glazing cells. When glazed, the pieces are placed on a kiln car and transported to the dedicated waiting line for the FFC-pieces by an AGV.

Figure 57 - Ifö Caprice washbasin 2162

The mid-range casting, MRC, production line produces vanity tops and washbasins, which because of their shapes needs to be made out of the FFC-slip. It consists of 4 casting cells, each press in every cell is of a one-piece type. This means that the production line can cast 4 pieces simultaneously. There are 8 dryers available for this line, which are shared with the small non-automated production line. One glazing cell is dedicated to the MRC production line. When glazed the pieces are placed on a kiln car and transported to the dedicated waiting line for the FFC-pieces by an AGV.

Inspection reporting concept

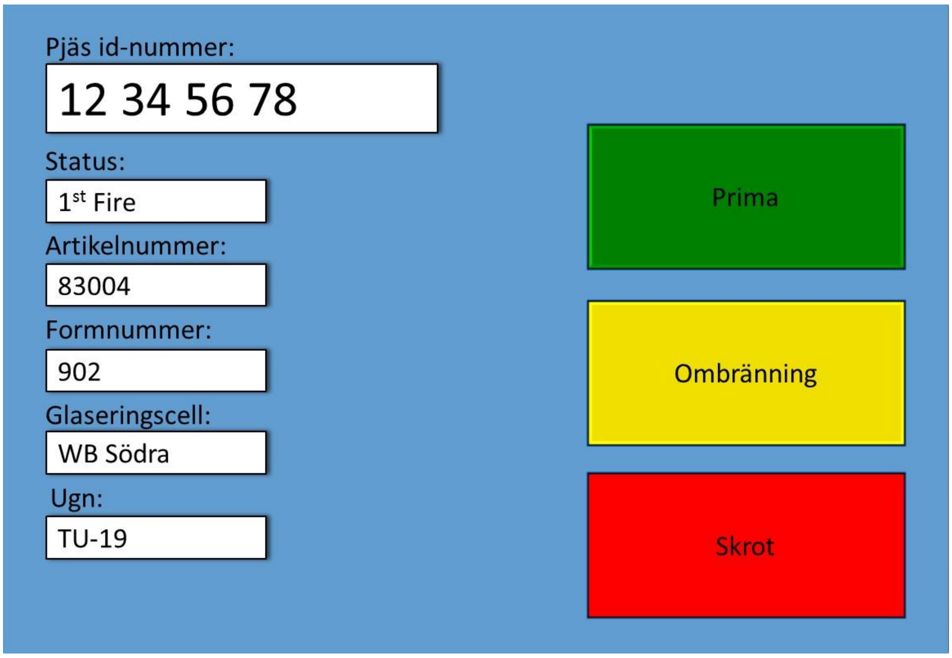

Figure 58 - After the inspector has scanned the piece, there are three choices availabe

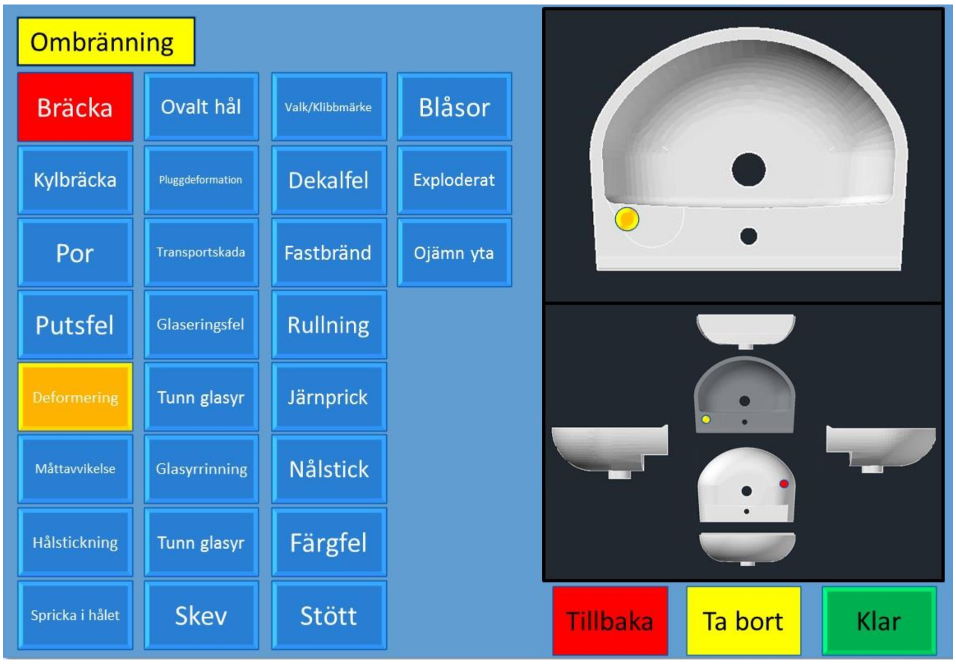

Figure 59 – If the piece is in need of re-fire or discarded, the inspector supplies all of the defect types and defect locations

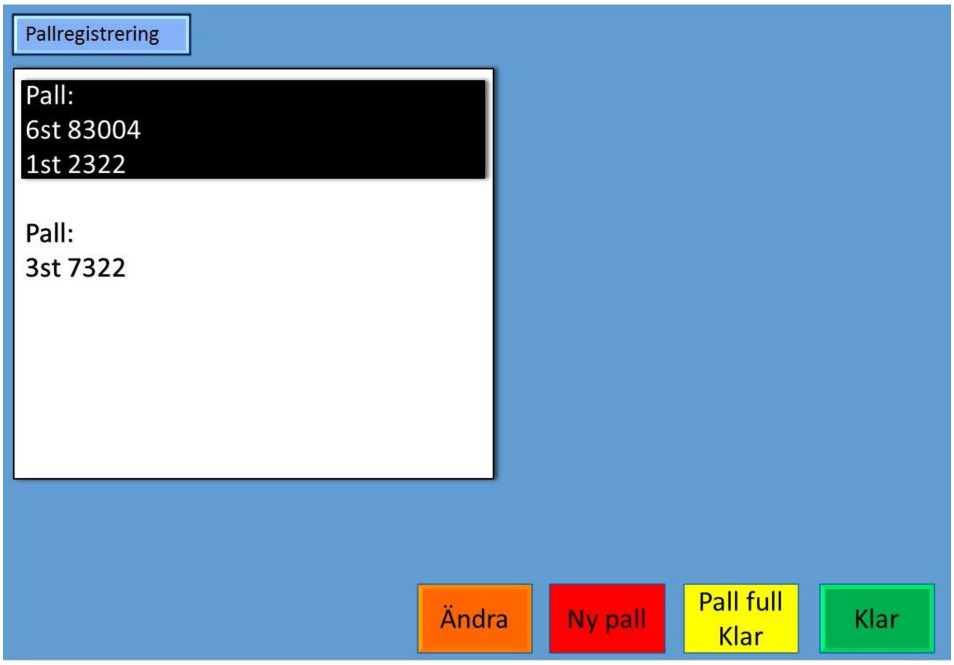

Figure 60 – In order to keep track on goods in need of re-fire a pallet connection is made by the inspector

Time savings survey

Tidsbesparingar vid införande av ett spårbarhetssystem

Vi undersöker för tillfället möjligheterna att införa ett spårbarhetssystem som är tänkt att ligga utanför ert ERP-system. För att få igenom en investering av detta slag måste vi även undersöka vilka kostnadsfördelar ett sådant system skulle inbringa. För att bringa klarhet i en av dessa kostnadsfördelar behöver vi er hjälp.

Ett idealt spårbarhetssystem skulle innehålla alla individer (pjäser) som produceras här i Bromölla. För varje individ skulle följande data registreras:

- Tidpunkt då individen inkommit och lämnat ett processteg samt vilken cell
- Eventuell sammankoppling med annan individ
- Sammankoppling med regal eller ugnsvagn, då individerna annars hade varit svåra att följa

I det ideala fallet skulle all antalsrapportering ske automatiskt genom hela produktionsprocessen. Den person som idag är ansvarig för att föra in antal, exempelvis gjutna eller glaserade, i ert ERP-system skulle i så fall ha möjlighet att rimlighetsgranska denna siffra innan den överförs från spårbarhetssystemet till ert ERP-system.

Varför?

Med ett välfungerande spårbarhetssystem hade tid som idag läggs på att t.ex. justera lagersaldon eller på att hitta en specifik produkt kunnat disponeras mycket bättre. Detta är tid som inte bringar något egentligt värde till produktionsprocessen utan är något som helt enkelt måste göras för att få den att gå runt. Denna tid borde istället kunna utnyttjas till att utveckla och förbättra produktionen.

Vad behöver vi av er?

Under tre veckor skulle vi vilja att ni dokumenterade all ”onödig” tid som läggs på att justera eller identifiera ett problem som enkelt hade kunnat hittas med ett spårbarhetssystem enligt ovan.

Vi har bifogat en mall där ni dag för dag kan lägga in hur mycket tid ni har lagt ner på att lösa problem av detta slag. Anledningen till att vi vill att detta förs in varje dag, i idealfallet varje gång man har lagt ner tiden, är att vi vill få en så pass god uppfattning som möjligt om tiden som läggs ner.

Här är några exempel på problem vars tidsåtgång vi tror hade minskat betydligt:

- Justering av lagersaldon (t.ex. L2, AW, L4)
- Justering av operationssaldon (t.ex. OP10, OP30)
- Efterrapportering

Mall för tid lagd på justeringar och efterrapporteringar

	19/3 tis	20/3 ons	21/3 tor	22/3 fre	25/3 mån	26/3 tis	27/3 ons	28/3 tor	29/3 fre	1/4 mån	2/4 tis	3/4 ons	4/4 tor	5/4 fre
Justering av lagersaldon (L2, L4, AW)														
Justering av operationssaldon (OP10, OP30)														
Efter-rapportering														
Total														