LAPPEENRANNAN TEKNILLINEN YLIOPISTO
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WELDING QUALITY ASSURANCE OF INTERNAL SUBCONTRACTORS IN SHIPBUILDING

Examiners: Professor Jukka Martikainen
M.Sc. (Tech.) Antti Itävuo

ABSTRACT

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Welding Quality Assurance of Internal Subcontractors in Shipbuilding

Master´s Thesis

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86 pages, 37 figures, 8 tables, 8 appendices

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The proportion of subcontracting is significant in welding of the hull structures. More complex and high-quality products are provided for customers keeping competitiveness in the global market. Thesis was aimed to develop tools for managing the welding quality of the subcontractors which weld under the quality system of the shipyard.

This constructive research used the statistics of welding defects and shortcomings of welder qualifications as research material. An experimental arrangement measured and analyzed the usage of welding procedure specifications. Data was analyzed by statistical methods.

Categorical variables are represented by frequencies. Numerical variables are represented by statistical key figures and also graphically. The reasons for the welding defects, which have the highest relative frequencies, were analyzed from theory. Defect lengths were compared to the inspection lengths of non-destructive testing. Correlation between the welding defects and welding in accordance with the welding procedure specification as well as the process of managing the welder qualifications were analyzed.

Managing the welder qualifications may be intensified by using a new process which is presented in this thesis. The welding in accordance with welding procedure specifications can be measured and analyzed by voltage, current, gas flow and travel speed. The measurable parameters do not exclude for example welding defects caused by impurities. Welding systems, which are based on Internet of Things, cannot ensure welding quality completely. The welding defects, the shortcomings of welder’s qualifications and the welding in accordance with welding procedure specifications can be measured continuously by introduced methods in this thesis.

TIIVISTELMÄ

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Sisäisen alihankinnan hitsauksen laadun varmistaminen telakalla

Diplomityö

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86 sivua, 37 kuvaa, 8 taulukkoa ja 8 liitettä

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Hakusanat: Alihankinta, telakka, laadunvarmistus, hitsaus, teollinen internet ja tilastotiede

Alihankinnan suhteellinen osuus on merkittävä laivan runkorakenteiden hitsauksessa. Asiakkaille halutaan tarjota entistä monimutkaisempia ja laadukkaampia risteilijöitä sekä autolauttoja säilyttäen samalla kilpailukyky globaaleilla markkinoilla. Työn tavoitteena oli kehittää työkaluja hallitsemaan telakan laadunhallinnan alaisuudessa hitsaavien alihankkijayritysten hitsauksen laatua.

Tässä konstruktiivisessa tutkimuksessa käytettiin tutkimusmateriaalina tilastoja hitsausvirheistä ja pätevyyspoikkeamista telakalla. Käytännön kokeena kehitettiin tapaa mitata ja analysoida hitsausohjeiden käyttöä. Data on analysoitu tilastotieteellisin menetelmin.

Tuloksissa ei-numeeriset muuttujat ovat esitetty frekvensseinä diagrammissa. Numeeriset muuttujat ovat esitetty tilastollisin tunnusluvuin ja graafisesti. Suhteellisesti suurimpien hitsausvirhetyyppien syitä on analysoitu teorian pohjalta. Hitsausvirhepituuksia on verrattu rikkomattomien menetelmien tarkastuspituuksiin. Korrelaatiota hitsausvirheiden ja hitsausparametrien välillä sekä hitsauspätevyyshallinnan prosessin sujuvuutta on analysoitu.

Hitsauspätevyyksien hallintaa saadaan tehostettua käyttämällä diplomityössä kuvattua uutta prosessia. Hitsausohjeissa hitsaamista pystytään mittaamaan ja analysoimaan jännitteen, virran, kaasunvirtauksen, hitsausnopeuden ja kaarienergian osalta. Mitattavat parametrit eivät sulje pois esimerkiksi epäpuhtauksista johtuvia hitsausvirheitä. Teolliseen internetiin perustuvilla hitsausparametrien seurantajärjestelmillä ei voida vielä varmistua kattavasti hitsauksen laadusta. Hitsausvirheitä, hitsausohjeiden noudattamista ja pätevyysseurantaa voidaan mitata jatkuvasti työssä esitetyillä tavoilla.

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Jaakko Salonpää
In Turku, 30th of November 2016

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LIST OF SYMBOLS AND ABBREVIATIONS

σ	Standard deviation of the individual observations
e	Expectations
E	Arc energy [kJ/mm]
IQR	Interquartile range
n	Independent observations from a population
N	Observations
P	Performance
Q	Quality
Q_1	First quartile
Q_3	Third quartile
s	Sample standard deviation
s_w	Length of the weld [m]
s^2	Sample variance
SE	Standard error of the sample mean
Δt	Time period [s]
$\bar{v}$	Average velocity $[\frac{\mathrm{m}}{\mathrm{s}}]$
w_{max}	The most up whisker
w_{min}	The lowest whisker
x_i	Variable
$\bar{x}$	Sample mean
Δx	Displacement [m]

3G	Third generation of mobile telecommunication technology
5S	Sort, straighten, shine, standardize and sustain (Comes from Japanese words: Seiri, seiton, seiso, seiketsu and shitsuke)
DIN	German Institute for Standardization
EN	European standard
ETO	Engineered to Order
HSE	Health Safety Environment

IEC	International Electrotechnical Commission
IoT	Internet of Things
IQR	Interquartile range
ISO	International Organization for Standardization
IWE	International Welding Engineer
IWS	International Welding Specialist
IWT	International Welding Technologist
JIT	Just-in-Time
NDT	Non-destructive testing
OHSAS	Occupational Health and Safety Management Systems
PDCA	Plan-Do-Check-Act
QC	Quality Control
R&D	Research and Development
RT	Radiographic Testing
SDAC	Standardize-Do-Check-Act
SFS	Finnish Standards Association
TPS	Toyota Production System
TQM	Total Quality Management
TWM	Total Welding Management
UT	Ultrasonic Testing
VT	Visual Inspection
Wifi	Wireless Local Area Network
WPS	Welding Procedure Specification

1 INTRODUCTION

Meyer Turku Oy is a family-owned shipbuilding company in Turku. Meyer Werft GmbH & Co. KG has owned the shipyard since 2014 when Dr. Jan Meyer became the Chief executive officer. Meyer Turku specializes in cruise ships, car-passenger ferries and special vessels. Over 1300 new ships have been built for multi-national customers since 1737. Competitive strengths are advanced construction processes, state-of-the-art technology solutions and cutting edge innovations for cruise operators as well as other ship owners. Piikkio Works Oy, Shipbuilding Completion Oy and ENG´nd Oy are the subsidiaries of Meyer Turku. An aerial view of the shipyard is shown in Figure 1. Today the Finnish maritime cluster has over 40000 employees working in manufacturing, technology, training, education over maritime industries and shipping. Meyer Turku is the major employer in the Southwest of Finland and has around 1400 employees. (Meyer Turku 2016.)

Figure 1. The shipyard of Meyer Turku (Meyer Turku, 2016).

Meyer Turku needs to increase production capacity after receiving a record-breaking number of orders in the following years. The capacity will be increased with investments and application of lean- philosophy side-by-side. The most remarkable investments are a new 1 200 tons gantry crane, panel line and updates for steel warehousing, preprocessing, plate and profile lines. Multiple plate fitter and pipe welder courses are organized yearly. White-collar workers have taken part in IWE/IWT (International Welding Engineer/International Welding Technologist) courses to increase their welding knowledge. (Itävuo & Forsström 2016.)

The management system of Meyer Turku complies with the Quality System Standard ISO (International Organization for Standardization) 9001:2008/3834-2:2005, Environmental System Standard ISO 14001:2004 and Occupational Health and Safety System Standard OHSAS 18001:2007 (Occupational Health and Safety Management Systems) (Quality Management Manual 2012, p. 2.). Standards ISO 9001 and ISO 14001 are updating to comply with the 2015 editions of the standards (Uusivirta, 2016).

The management process of the qualifications of subcontracted welders does not have a clear description and that is why responsibilities are decentralized. In some cases subcontracted welder starts welding work before their qualifications and competence are checked by Meyer Turku. Development and clarification of the welding quality procedures have been started to be improved quality and productivity of welding. The research in this thesis has been started as a part of these improvements.

1.1 Objective, limitations and research questions

This research aims to introduce a proactive control method for improving the welding quality of internal subcontractors. They weld under the quality system of Meyer Turku in the area of the shipyard. The proactive control must be easy to use and scalable for a larger number of subcontractors in the future. Quality issues which were not caused by the welders of subcontractors are left out of this thesis.

Based on the objective, four research questions are presented:

- What is the best process of updating the qualification register of the welders?

- How the welding process in accordance with WPS (Welding Procedure Specification) can be measured?
- What are the benefits of the different quality assurance tools such as a real-time data monitoring and preproduction test in Meyer Turku?
- What is the best way to manage the welding quality of the subcontractors?

1.2 Research methods

This thesis was a constructive research and investigated by interviews, quality records and random sampling of the welding parameters of the subcontractors. Quality, procurement and production departments as well as the subcontractors are interviewed for establishing an overview of the qualification management for the subcontractors. Potential problems are investigated by analyzing the qualifications for errors (e.g. what is the average delay time to receive 6 months prolongations from the subcontractors).

The frequency of the welding defects was determined from NDT- records (Non-destructive testing) of one ship. These defects were compared to random sampled WPS inspections. Their equipment and testing arrangement as well as compilation of statics on inspection are introduced in the method section. Suitability and benefits of the quality management philosophies and quality assurance tools in the case of the shipyard were considered.

2 THEORY

This chapter contains phenomenon and concepts behind this thesis. Quality is introduced in Chapter 2.1. Main welding quality management standards are introduced in Chapter 2.2. Chapter 2.3 shows quality manual, process descriptions and work instructions, standards and guidelines of Meyer Turku. Chapter 2.4 introduces quality management philosophies in welding network. Common subcontracting legalisms in Finnish maritime cluster and quality assurance differences between own and subcontracted welders are introduced in chapter 2.5. Internet of Things is demonstrated in chapter 2.6.1 for quality assurance tools in chapter 2.6.

2.1 Quality

Normally quality is connected to an excellent product or service which fulfills or exceeds our expectations. If the selling price is higher than comparable products or services, it is expected to be better. Usually the performance of the product is considered to be high-quality if the performance fulfils the expectations. Therefore, quality can be defined as (Besterfield et al. 2011, p. 6)

$$Q = \frac{P}{e} \tag{1}$$

, where Q is quality, P is performance and e is expectations. The product will fulfill expectations if Q in the equation 1 is higher than one. (Besterfield et al. 2011. p. 6–7.)

Another way to define the quality is to separate it into five principal approaches. These are defined as follows:

1) *Transcendent:* Quality cannot be defined but it is something good.
2) *Product-based:* Similar products do not have same value adding features.
3) *User-based:* Customer expectations meet characteristics of the product.
4) *Manufacturing-based:* Manufacturer aims to fulfill requirements and standards of the product
5) *Value-based:* Price and features are mixed for the best result.

(Rumane 2011, p. 7.)

Overall, quality is subjective and does not have a measurement unit. If quality is defined differently between departments, the results will be dissimilar. Generally the quality of the product is defined by customer satisfaction. The manufacturing-based quality can be perfect even if the user-based quality does not meet the requirements. On the other hand the customer is not ready to pay for too high product-based quality. For example, the users do not use every button of the remote control of the modern television. They do not want to pay for it. Improvement of quality has become a major business sector with large amounts of quality management literature and consults offering their services. The tools for improvement are available but often quality philosophy is not defined by needs of the company. If something is not defined, it is unmeasurable. If something is unmeasurable, it is not managed. (Multimäki 2003, p. 28–30.)

2.1.1 Quality costs

The most common way to measure quality costs separate the costs into prevention costs, appraisal costs as well as internal and external failure costs. The total quality costs are the sum of those. (Douglas 2012, p. 5.) Different quality costs are shown in Figure 2.

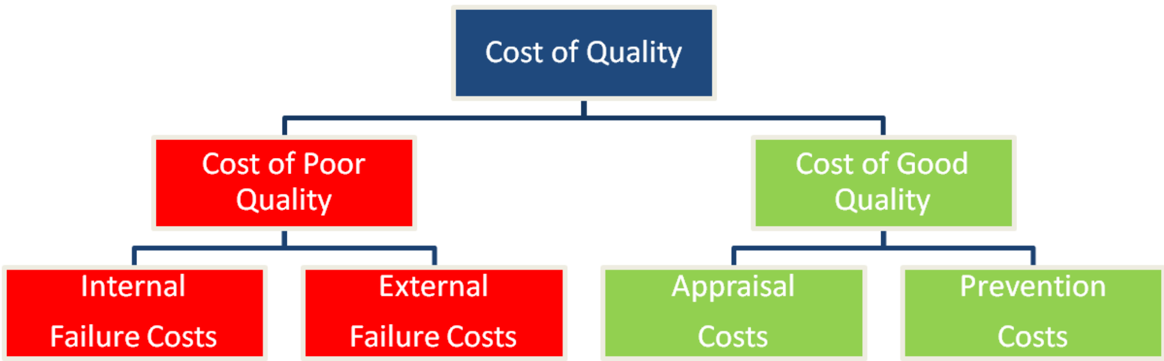

Figure 2. Cost of quality (Buthmann 2016).

The internal and external failure costs are the costs of the poor quality which has already manifested as failures. The internal failure costs are results from failures in the product or service. The failure has been found before delivery to an external customer. The internal costs can be caused by reworking, reinspecting and retesting as well as reviewing and downgrading material. The external failure costs are results from failures after a delivery to the customer. Product recalls, customer returns, warranty claims and processing customer complaints are examples of the external costs. (Douglas 2012, p. 5; Buthmann 2016.)

The prevention and appraisal costs are quality control costs. The prevention costs are caused by activities for preventing the poor quality in the products or services. Quality and management system costs, new product reviews, quality team meetings, quality projects, process capability evaluations, quality training and education are examples of the prevention costs. The appraisal costs are caused by controlling, testing, measuring and other systematic processes for ensuring high quality. Costs of incoming and source inspection for materials and audits are examples of the appraisal costs. (Douglas 2012, p. 5; Buthmann 2016.)

A significant amount of the quality costs is hidden because most accounting systems cannot identify and track them. Quality problems are handled typically by calling and emailing. The signs of the problems are hidden under new emails and calls. Top management looks at the overall costs over the quality costs because the accounting of the quality costs is difficult. The competitiveness of the company is threatened by increasing quality costs. If the hidden costs can be revealed, the management will guide resources to remove problems and respond to the demands of the customer. Figure 3 shows the difference between measurable and hidden failure costs. (Douglas 2012, p. 6–8.)

Figure 3. Hidden costs of the quality (Douglas 2012, p. 7).

The highest quality costs are caused when the customer finds defects. If the defects are found during inspection or testing, the quality costs will be reduced. The quality costs can be optimized with a cost-efficient quality system that finds the defects effectively. An older version of the optimal quality cost is shown in Figure 4. It also shows that when we are approaching the defect-free level, appraisal and prevention costs rise asymptotically. (Douglas 2012, p. 8.)

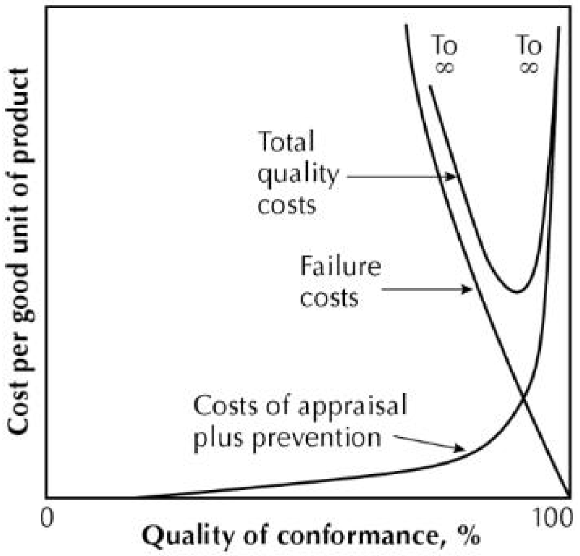

Figure 4. The older version of the optimal quality costs (Douglas 2012, p. 9).

Strong evidence points out cost-effectiveness can be increased with process improvements and loss prevention. Robots and other forms of automation have reduced faults in production and inspection which have previously been caused by human errors. These developments enable ability to achieve perfection at finite costs. The principle of a new loss prevention is shown in Figure 5. It shows total quality costs are the lowest when defect-free level is reached. Then total quality costs contain only appraisal costs. Quality management bases on measuring quality costs. (Douglas 2012, p. 8, 10.)

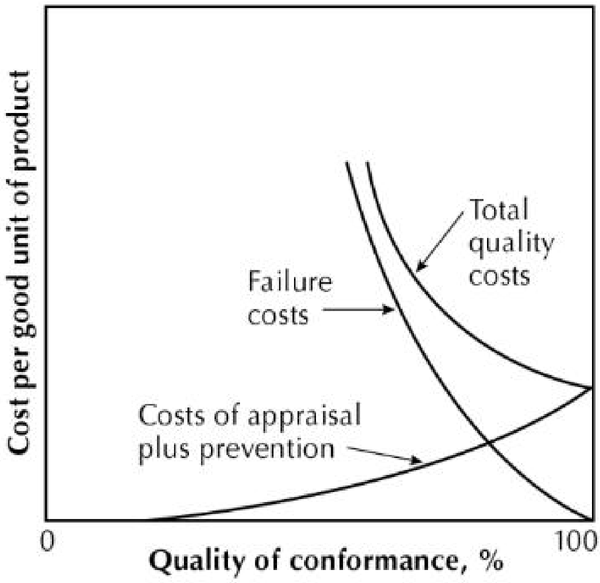

Figure 5. The current version of optimal quality costs (Douglas 2012, p. 10).

2.1.2 A quality management system

Building a quality management system is started by understanding external perspectives. A feedback system must be established for transferring information between own organization, suppliers and customers. The organization can be seen as a series of suppliers and internal suppliers as well as customers whose work is the core of quality improvements. Internal customers and suppliers must be measured for managing their capability. The processes of an organization must be defined because they make inputs into desired outputs. Therefore working processes and potential risks can be determined. The systematic activities of quality assurance can be defined for managing the potential risks. Top management must commit to continuous quality improvements that everyone else in the organization can co-operate together continuously. A quality management system can be founded according to quality management standards and philosophies. (Oakland 2014, p. 1, 17, 18.)

2.2 Standards of quality management

The general outline of SFS-EN ISO 9001 (Finnish Standards Association; European Standard) and SFS-EN ISO 3834 are introduced in this chapter. ISO 9001 standard is a strategic standard for managing an organization while ISO 3834 standard is designed for industries which use the fusion welding of metallic materials. (ISO 3834-1 2005, p. 4; ISO 9001 2015, p. 5.) Mentioned ISO 14001 is an environmental management system and it provides a framework that organizations can fulfill their environmental responsibilities in balance with socio-economic needs in long term (ISO 14001 2015, p. 5).

2.2.1 General outline of SFS-EN ISO 9001

A quality management system is one strategic part of an organization. Implementing the quality management system, the organization can improve its overall and continuous performance. On ISO 9001 standard based quality management system provides better opportunities to achieve higher customer satisfaction, recognize risks and possibilities. A content of ISO 9001 standard is shown in appendix I. (ISO 9001 2015, p. 5.)

The organizations must recognize and manage connected activities to be effective. A process means an action which is managed and uses resources. The process makes possible the transformation of inputs into outputs. The process approach means the system of processes where interactions and identification between the processes and management are observed. The benefits of the process approach include an ongoing control over all systems and individual processes as well as the combinations and interactions of the processes. (ISO 9001, 2000, p. 11.)

ISO 9001:2015 standard uses PDCA cycles (Plan-Do-Act-Check-Act) with risks-based thinking. With the PDCA cycles an organization ensures processes have resources and management as well as improvements are exploited. The risks-based thinking ensures that factors, which can unbalance the processes, are noticed for limiting the disadvantages. The PDCA cycles are introduced in Figure 6. (ISO 9001 2015, p. 5.)

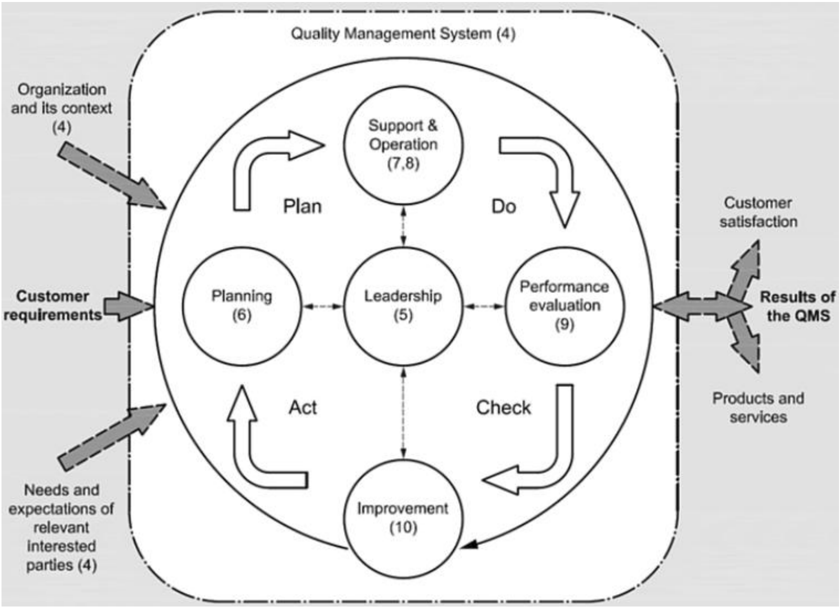

Figure 6. PDCA cycle (ISO 9001 2015, p. 7.)

2.2.2 General outline of SFS-EN ISO 3834

In many companies welding is a key process in manufacturing. The range of products that use welding is wide, ranging from pressure vessels to transport vehicles. When welding is the major process its influences on quality and the costs of manufacturing are remarkable. (ISO 3834-1 2005, p. 7.)

ISO 3834 standard covers the quality requirements for the fusion welding of metallic materials. ISO 3834 standard is not a quality requirement system standard for replacing ISO 9001 standard, but its welding specialties can be used to complement ISO 9001 standard. ISO 3834 standard consists of the six parts which define the extent of requirements. Higher quality levels fulfil also lower levels. (ISO 3834-1 2005, p. 4, 7, 13.) According to ISO 3834-1 standard (2005, p. 5) the parts are as follows

- “Part 1: Criteria for the selection of the appropriate level of quality requirements
- Part 2: Comprehensive quality requirements
- Part 3: Standard quality requirements
- Part 4: Elementary quality requirements
- Part 5: Documents with which it is necessary to conform to claim conformity to the quality requirements of ISO 3834-2, ISO 3834-3, ISO 3834-4
- Part 6: Guidelines on implementing ISO 3834”

The necessary level of quality requirements is based on a number of criteria. They are safety aspects, complexity of manufacture, quantity of different products and materials, effects of metallurgical problems and manufacturing imperfections. The right level of the quality requirements can be chosen by using the levels of ISO 3834 from the appendix II. (ISO 3834-1 2005, p. 11–13.)

Requirements, acceptance limits, specifications, processibility with tools, instructions and the qualifications of suppliers must be checked during the review of requirements and technical review. The manufacturer is responsible for subcontractors fulfill the requirements. (ISO 3834-2 2005, p. 7, 11; Toikka 2008, p. 15.) The review of the requirements and the technical review must be carried out based on the needs of the company instead of copying the list of ISO 3834 standard. The hiring procedure must be standardized if several different persons within the company hire subcontractors. The success of subcontractors can be documented to support decision-making. Usually buyers blame the subcontractors because they think the subcontractors are unskilled. In reality the root cause is likely somewhere else. One reason can be the buyer has not sent coverage information of the requirements of a product and all needed documents to the subcontractors. (Toikka 2008, p. 15.)

Welders, welding operators and NDT testers must be qualified. Responsibilities, deputies, authorities and tasks must be defined. Welding coordination personnel, who have responsibilities of the quality, must be authorized to carry out necessary quality activities. (ISO 3834-2 2005, p. 11.) The International Institute of Welding has recommended IWE (International Welding Engineer), IWT (International Welding Technologist) or IWS (International Welding Specialist) for the welding coordination personnel (ISO 14731 2006, p. 4).

ISO 3834 standard requires essential equipment must be listed and described in production. The essential equipment influences to capacity and capability of a workshop. (ISO 3834-2 2005, p. 13.) Equipment maintenance must be performed according to the recommendations of machine manufacturer and documented. For example, the sticker of the next maintenance date can be glued on the equipment. The law requires that lifting accessory must be inspected every year. Color codes are used to indicate when the lifting equipment needs to be inspected. The color code system can also be used for other equipment inspections. Normally companies do not have an inspection plan for ovens and quivers which are used for welding consumables. (Toikka 2008, p. 16.)

An adequate production plan must be documented. The production plan verifies that actions are planned and carried out at the right moment. ISO 3834-2 standard lists the adequate actions. (ISO 3834-2 2005, p. 15.) However, usually manufacturers will copy the list of the actions without thinking about the essence of the list. (Toikka 2008, p. 16).

WPS must be prepared by the manufacturer who is responsible for production. Product standards and specifications define methods of a qualifying process. The correct usage of WPS must be ensured in production. In addition the manufacturer can prepare work instructions which do not need separated qualifications. (ISO 3834-2 2005, p. 17.) Companies have used significant amount of resources to develop extensive libraries of approved WPSs. Unfortunately the production rarely uses these libraries. Many companies do not even have a procedure for testing how well welders are in the range of WPSs. (Toikka 2008, p. 16.)

Parent metal storing must be trackable so that identifying is possible if necessary. The responsibilities and instructions of controlling welding consumables must be specified. If batch testing is specified, it is required. The moisture pick-up, oxidation and damage of welding consumables can be avoided by right procedures. The manufacturer must generate and implement the procedures for the storing, handling, identifying and using welding consumables. The instructions must be based on the recommendations of suppliers. (ISO 3834-2 2005, p. 17.) The manufacturer normally copies the instructions of suppliers but unfortunately forgets to ensure these instructions are also followed. The welding consumables must be taken back to storage before long breaks. (Toikka 2008, p. 17.)

Manufacturers have a full responsibility for defining and carrying out post-weld heat treatments. It must be suitable for the parent metal, welding consumables, welded joint, construction and other variables in accordance with specified requirements and product standards. The record of the post-weld heat treatment must be monitored. (ISO 3834-2 2005, p. 17.) Manufacturers use specialized subcontractors for the post-weld heat treatments and that is why problems do not occur in the post-weld treatments. Preheating and heat straightening are more common problems. Also these must be documented and defined. (Toikka 2008, p. 17.)

The products and processes used by the production must be inspected and tested before, during and after welding. These are performed by a welding coordinator and the welder. The welding coordinator checks the suitability and validity of the qualifications of the welder and WPS. The welder checks parent material, joint preparation, consumables, parameters and special requirements. Welding in accordance with the WPS should be followed and recorded. (ISO 3834-2 2005, p. 19.) Normally the visual inspections are not recorded which are performed by welders (Toikka 2008, p. 17). Also non-destructive testing, destructive testing, forms as well as the shapes and limitation of a construction and the results and records of post-weld operations must be checked with relevant acceptance if these are required. (ISO 3834-2 2005, p. 19).

A procedure is needed for non-conformance and corrective actions. The quantity and quality of defects must be tracked and analyzed. Authors must be defined for reporting and handling. Actions have to be defined for preventing repeated errors. (ISO 3834-2 2005, p. 20.) The statistic of deviations can be used to reduce quality issues. However, usually any issues are just corrected without logging the deviations. This makes it more complicated to separate and analyze the types of defects for proactive actions. Because of this, continuous improvement is not performed. (Toikka 2008, p. 17.)

The appropriate validation or calibration of measuring, testing and inspection equipment are required from the manufacturer. The equipment which is used for inspection of quality must be inspected, calibrated and approved. (ISO 3834-2 2005, p. 21). The most general inspection and testing equipment on the shop floor are a foot rule and a slide caliper. Pressure, heat, current and voltage meters are calibrated with calibrated meters. If tolerances are tighter than normally, investment into a calibrated master meter will be justified. (Toikka 2008, p. 17.)

Identification, traceability and quality records are not required in ISO 3834 standard. But these are performed well in companies because requirements come usually from the product standards. Documents give information about mistakes in production. (Toikka 2008, p. 17.)

2.3 Quality management at Meyer Turku

The management system of Meyer Turku complies with the Quality System Standard SFS-EN ISO 9001:2008/SFS-EN ISO 3834-2:2005, Environmental System Standard SFS-EN ISO 14001:2004 and Occupational Health and Safety System Standard OHSAS 18001:2007. The sales, design, manufacturing, lifecycle services of vessels and structures cover the needs of offshore customers and ship owners. The products and services are also covered by the environmental system. The management system of Meyer Turku is separated into four levels which are (Quality Management Manual 2012, p. 2.):

- Level A – Quality manual
- Level B – Process descriptions
- Level C – Work instructions
- Standards, guidelines issued by the authorities and reference instructions.

2.3.1 Level A – Quality manual

Quality policy and occupational health, occupational safety and environmental policy as well as the central operating principles, responsibilities, handling and supervising of the operations of the company are shown in a quality manual. It is approved by the managing director of the company. The quality manual is distributed, updated and stored by the quality manager. (Quality Management Manual 2012, p. 2.)

The quality policy aims to offer the best solution for customers. Vessels must create profit to the customers during its lifecycle which requires openness and co-operation between Meyer Turku and its customers. Satisfaction, competitiveness and responsible finance are the base of trust. The goals are achieved with committed and skilled personnel and suppliers which have committed to continuous improvement. In the vessel building process the next department is an internal customer for the previous. Only products and services, which fill the requirements, are delivered to the internal customer. (Quality Policy 2012, p. 1.)

2.3.2 Level B – Process descriptions

The operation principles, input- and output material and indicators are described for ensuring effectiveness. The authors of different processes with other relevant persons in charge define and publish as well as ensure the compatibility of descriptions in co-operations. The authors review and update the process descriptions if necessary. The company management group confirms the process descriptions. These are checked and filed by the quality manager. (Quality Management Manual 2012, p. 2–3.)

The hull production process aims to deliver grand block sections with the agreed level of outfitting and surface treatment to hull assembly. The hull assembly aims to assemble an approved ship hull for a launch. The hull production are separated into detail design, work planning, part fabrication and assembly, block assembly, grand block assembly, block outfitting phases, surface treatment and subcontracting. (Hull Production 2011, p. 1–4)

The products of the part fabrication are cut plate and bent profile parts. The needs of assembly department define how the parts are sorted and produced. The products of the part assembly are pre-assembled, partly outfitted units which are divided into product families. These determine assembly locations and manufacturing methods. The block assembly includes panel lines, dock section assembly halls and block halls. Flat blocks are assembled in the block lines and sites. The units of the part fabrication, block assembly, sub-contracted floating hull parts or blocks are assembled together at the grand block assembly. The production departments with a procurement organization are responsible for the subcontracting. A project execution plan defines sub-contracted blocks and floating hull parts. (Hull Production 2011, p. 1–3.)

In Meyer Turku the welding engineer is responsible for welding-related activities including the internal subcontracting. The NDT engineer is responsible for NDT-related activities. The welding engineer ensures that welding procedures specifications are available for all used project materials, welding processes, welding positions and welding consumables as well as the defining of a qualification process for welding operators and welders in the area of the shipyard. Project-specific requirements are also managed by the welding engineer. The welding-related quality is analyzed and corrected by the welding engineer. Creating

NDT plan, NDT implementation planning, resource acquisition and the implementation to a project are managed by the NDT engineer. (Welding and NDT 2011, p. 1–2.)

2.3.3 Level C – Work instructions

The performance of a work or task is described in the work instructions. The departments are in charge of issuing and filling work instructions. (Quality Management Manual 2012, p. 3.)

The head of the production planning of Meyer Turku is responsible for conducting the first review of requirements. Quality and project hull manager arrange the review of requirements meeting after an agreement is signed up. The technical review is performed soon as possible after the agreement is signed by the project hull manager, QC (Quality Control) engineer and welding engineer. The production departments are responsible for saving quality documents into a document quality management system. (Welding Coordination 2014, p. 1–2, 5.)

The defining of technical needs and investment proposition as well as applicability for welding equipment is managed by the welding engineer. The equipment register, maintenance and instructions of maintenance are managed by the maintenance department. Qualifying production equipment is managed by the production departments. (Welding Coordination 2014, p. 2.)

The construction methods of a production planning are managed by the head of the production planning of hull production. The construction methods include planning of efficient manufacturing methods, order of welding and special requirements for the direction of the groove openings as well as special requirements which came up in the technical review. The head of the detail design of the hull production is responsible for work material is connected to appropriate welding and other instructions. (Welding Coordination 2014, p. 3–4.)

The welding engineer answers for managing filler materials suitability for the used materials. The acquisition, handling and storing of welding consumables are defined. The purchasing, storing, handling and traceability of materials are managed by the production planning of the material department and hull production. (Welding Coordination 2014, p. 5.)

WPSs are defined according to SFS-EN ISO 15609-1, SFS-EN ISO 15614-1 + A1 + A2 and SFS-EN ISO 15614-2 as well as the standards of Det Norske Veritas and Lloyd's Register (Welding and NDT, 2011, p. 1). The production departments are responsible for their welders welding in accordance with WPS. If new welding processes or materials are adopted, new welding procedure tests must be performed. The WPSs are saved in a documentation management system. Supervisors are responsible for the welders have the appropriate WPSs of an ongoing project. (Hitsausohjeet (WPS) 2016, p. 1–2.) Post-welding heat treatments are defined as special requirements in the technical reviews. The post-welding heat treatments are defined by the welding engineer. The supervisors are responsible for the instructions are followed in his or her areas. (Welding coordination 2014, p. 5.)

Defining the needs of the qualifications of welders and the welding documentation of qualification procedure is managed by the welding engineer. The welders and welding operators are qualified according to SFS-EN ISO 9606, SFS-EN ISO 14732 and SFS-EN 287-1. The validity of the qualifications would be 3 years if it is extended every 6 months under ISO 9606 standard. The validity of the qualifications would be 2 years if it is extended every 6 months under ISO 287-1 standard which is expiring after transition period. The supervisors are responsible for their welders have right qualifications for welding tasks. Every supervisor responds their welders are qualified before they start welding in production. A named person of Meyer Turku is responsible for managing the qualifications of the welders of subcontractors. The person sends all qualifications to a qualification register and ensures the qualifications are prolonged every six month. (Hitsaajien pätevöitys 2016, p. 1, 3.)

Checking that welding parameters are within the limits of WPS must be performed and written down in the production departments by appointed persons. Corrective actions must be performed if the welding parameters are not in accordance with WPS. Also the functionality of used WPS is checked for a construction. In the end the welding parameters must be corrected. A welding unit must be taken off to the maintenance if the welding parameters of a welding unit differ significantly. The record of parameters checking is sent to the welding engineer. (Hitsausarvojen tarkistus 2016, p. 1–3.)

Hull and its welds as well as demanding outfitting welds are visually inspected. The department managers of manufacturing departments controlling, the instructions are followed. The managers and supervisors are in charge of quality requirements and production plans are filled. The supervisors are also responsible for ensuring that construction and welds are inspected and fixed if it is needed. Every worker must visually inspect their works and carry out any needed corrections. In addition, every weld must be identified using chalk. (Rakenteen ja hitsien silmämääräiset tarkastukset 2015, p. 1.)

Fitters are responsible for ensuring that tack welding and aiming have been performed right. Weld grooves must be cleaned from impurities and prefabricated in accordance with WPSs. The fitters also check every part is installed. Before starting the welders check work site is aimed, gapped, chamfered, preheated, cleaned and dried in accordance with WPSs. The welders check their work continuously during welding. The quality level of welds is C for steels without incomplete penetration in accordance with SFS-EN 5817. The welders perform the 100 % visual inspection for every weld. Throat thicknesses are measured by a welder and random checks. The supervisors are in charge of works, constructions and welded welds are inspected. The supervisors are responsible for mistakes and defects are corrected immediately. The supervisors order NDT-inspections and organize proper working conditions to welders and fitters. (Rakenteen ja hitsien silmämääräiset tarkastukset 2015, p. 2.) The supervisors are responsible for proactive quality activities and repairs in their areas. In addition the welding engineer defines spot checking before, after and during welding. (Welding Coordination 2014, p. 5.)

Welders must identify their welds. With marked welds the welders can get feedback directly. All butt and fillet welds as well as T-joints must be marked in the part fabrication, block assembly, grand block assembly and hull erection. The butt welds, full penetration T-joints as well as sleeve and butt joints of pipes must be marked in demanding outfitting. Responsibilities have been shared as follows. The department managers of manufacturing departments ensure the instructions are familiar and complied. The supervisors are responsible for the welds are marked right. Making correct markings are managed by the welders. The identifier means the weld is finished, visual inspected and ready for NDT inspection. The identifiers marking are shown in Figure 7. The starting point of a weld and welding direction must be marked by an arrow. Yellow or black water based water-proof marker pen must be used. If several welders work on the same welds, they have to separate their identifiers. (Hitsaajatunnusten merkintä 2015, p. 1–2.)

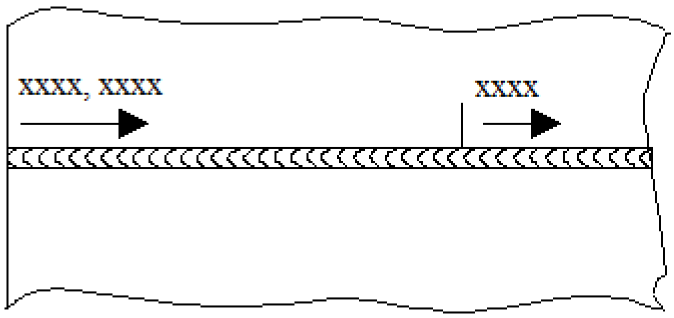

Figure 7. How to identify welds (Hitsaajatunnusten merkintä 2015, p. 2).

2.3.4 Standards and guidelines

The development, maintenance and filling of standards are managed by one person at each site (Quality Management Manual 2012, p. 3). Standardization is the foundation for quality and safety as well as continual improvement. It consists of activities to define procedures for common and repeated tasks. The goals of standardization are cost savings, reduction of material diversity, low material variation, defined installation and application areas, improved production and quality, safety and environmental awareness, optimized research and technology as well as making ships together. The principle of continual improvement and breakthrough improvement are shown in Figure 8. (Laakeristo 2016a, p. 2–7.)

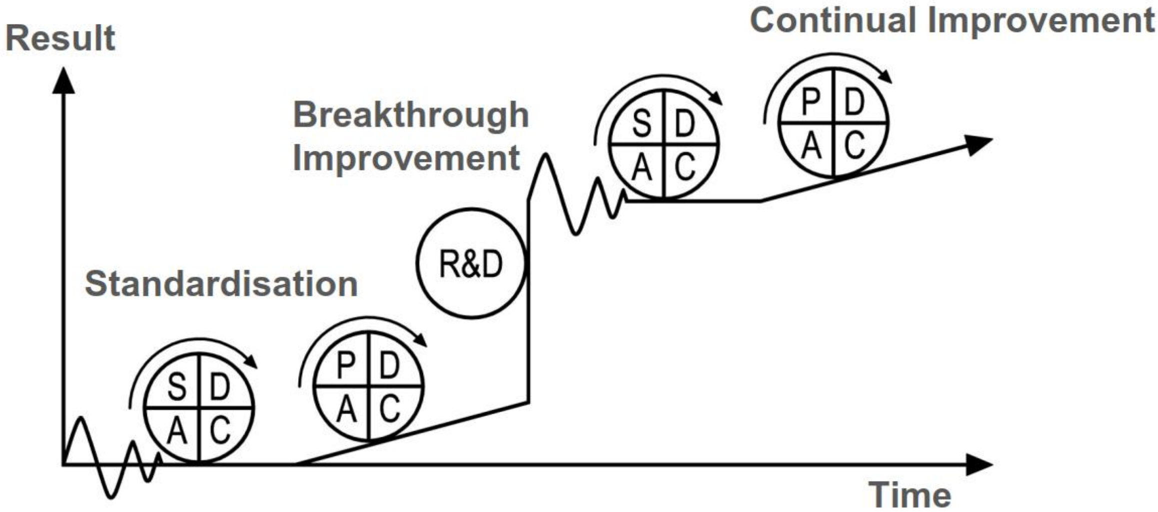

Figure 8. The principle of continual improvement and breakthrough improvement where occurs Standardize-Do-Check-Act (SDCA), Plan-Do-Check-Act (PDCA) as well as Research and development (R&D) (Laakeristo 2016b, p. 5).

Standardization can be used on every level of the organization in Meyer Turku. It is also good to keep in mind that every new idea is not good. New ways can be find systemically and curiously. The types of standards at Meyer Turku are shown in Figure 9. (Laakeristo 2016, p. 2–7.) At Meyer Turku the welding coordination is implemented according to ISO-EN 3834 with its linked standards. (Welding Coordination 2014, p. 2).

Figure 9. ISO, IEC (International Electrotechnical Commission), EN, DIN (German Institute for Standardization), SFS and Meyer standards as well as technical specifications are used at Meyer Turku (Laakeristo 2016, p. 9).

2.4 Quality management philosophies in welding network

Lean, total quality management and total welding management are introduced in this chapter. The philosophies have similarities and they can be applied together or separately.

2.4.1 Lean

The origin of lean comes from automotive production of Toyota in Japan. Toyota could not complete against Henry Ford with their resources. That is why Toyota needed to develop TPS (Toyota Production System) that is called Lean nowadays. Lean has also been applied in different kinds of businesses like construction and design. Lean aims to eliminate waste and focus on adding value to improve the satisfaction of the customers. Lean bases on a continual improvement process. The basic principles of lean are shown in Figure 10. (Phogat 2013, p. 85.)

Figure 10. The basic principles of Lean (Phogat 2013, p. 85).

The first step of lean defines the parts of production which create added value to the customers. The core values of an example production process are introduced in Figure 11. Value management, function deployment and simulation can be used for investigating problems. The second step generates the map of a value stream for understanding how the core value for the customer is made through the process. Making value stream and one-piece flow are the third step. Batches and queues should be avoided or reduced. On the fourth step JIT (Just-in-Time) and standardization are started to be used. Then products are only produced by the needs of the customers. The last part aims to seek perfection. When the five steps are made continuous improvement, waste elimination and evaluation of the changing process must be carried out continuously on every step. (Phogat 2013, p. 85.)

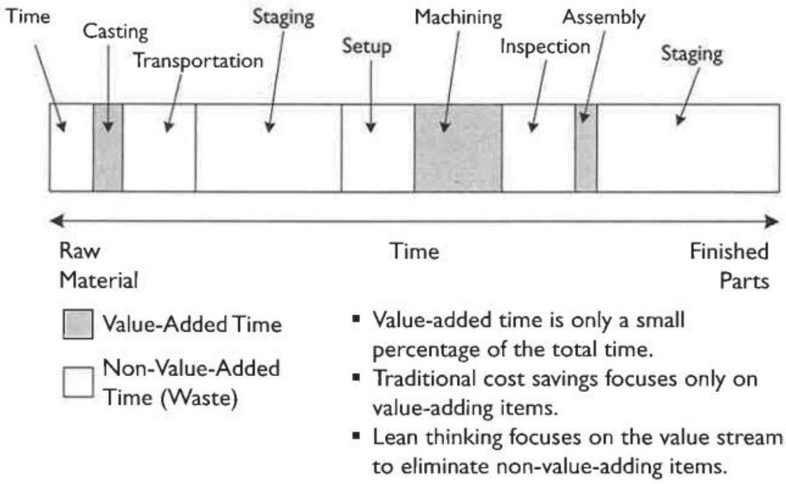

Figure 11. The core value to the customer (Liker 2004, p. 30).

Inspected quality often is temporary quality. It is easy to inspect an assembled product for repairing quality problems. However it does not remove the quality problems in a process. An industrial quality standard like ISO 9000 has all kinds of detailed procedures. That makes the companies to believe they have a detailed quality book is followed. Usually the quality management department analyzes data and has a lot of technical methods to correct issues. The Toyota way, on the other hand, is simpler there is usually only a couple of complex statistic tools. The method is based on going to see, analyze the situation, inform about issue and ask five times why. This simplicity has been seen to be the power behind the quality in Toyota. (Liker 2004, p. 135.)

A well-planned lean system implements 5S as a tool, which is named by Japanese words seiri, seiton, seiso, seiketsu and shitsuke. The tool can be a part of process of visual-control supporting smooth flow and takt times in lean production. 5S is the series of activities to eliminate errors, defects and injuries in workplaces. It can be translated to sort, set in order, shine, standardize and sustain. The tools of 5S are sorted by usage. Rarely used tools are moved outside from a working area. Every tool must have a specific place in the working area. Shine means tools are cleaned every time after using them so that the issues of the tools can be found faster. (Liker 2004, p. 150–152.)

Lean shipbuilding has been established, for example, in Norway, Japan and United States. Norwegian shipbuilding industry has often ETO (Engineered to order) projects. That is why their procedures are highly customized, the degree levels of outfitting are high and constructions are special. Executing vessels, Norwegian shipbuilding industry uses different subcontractors and suppliers. In Norway lean construction and lean shipbuilding are blended to one production concept due to the nature of the shipbuilding industry. The practical experiences of lean have revealed being a good tool for a cultural change in the United States. Lean involves analytical thinking when improvement can be achieved. Payback is covered in a short period. Japanese shipbuilding industry has been exemplary in the terms of productivity and product quality. For example, Japanese shipyards implement JIT, highly standardized and timed processes as well as every employee follows the quality of production processes. The Japanese shipyards are driven by a pull production on the top level and mixed schedules on the bottom. It is wanted to be avoided that upstream schedule is not ruined if production drops in the downstream stage. (Phogat 2013, p. 87–88.)

2.4.2 Total Quality Management

TQM (Total Quality Management) is a philosophy and a set of principles focusing on continuously improving organizations. TQM concentrates on the changing actions of management so that the culture and actions of a whole organization can be transformed. All processes, organizations and needs of customers can be improved by the applications of human resources and quantitative methods. Common sense is the major part of the TQM. (Besterfield et al. 2011, p. 1.) Besterfield et al. (2011, p. 1) has explained the golden rule of TQM as follows: “Do unto others as you would have them do unto you”. TQM can be separated in six concepts as follows (Besterfield et al. 2011, p. 2):

1) A long-term top-to-bottom organization which is supported by the management.
2) Internal and external customers are observed continuously.
3) Every employee is effectively involved and utilized.
4) The business and production process must be developed continuously.
5) Suppliers are treated like partners.
6) Measurement of process performance.

The framework of the TQM is shown in Figure 12. The framework starts from quality experiences of so-called “gurus”. The gurus are Shewhart, Deming, Juran, Feigenbaum, Ishikawa, Crosby and Taguchi. They have their own developing principles, practices, tools and techniques. (Besterfield et al. 2011, p. 5.)

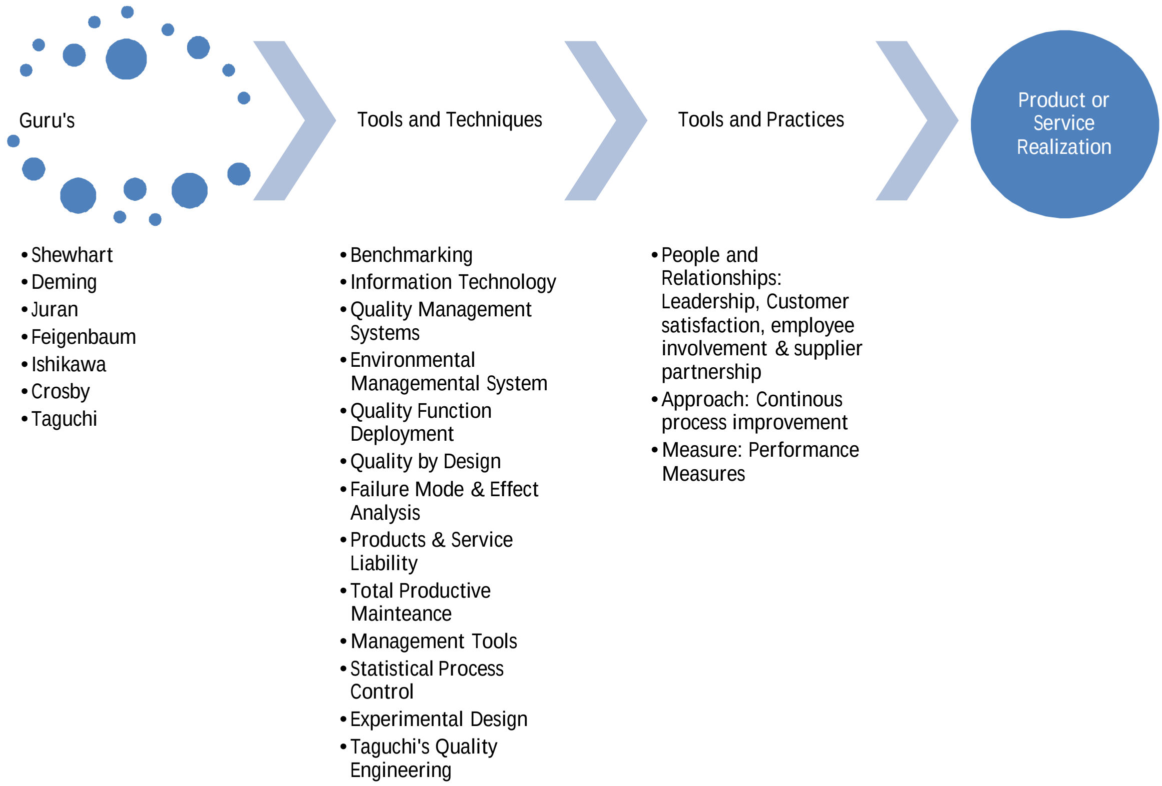

Figure 12. The framework of TQM (Modified from: Besterfield et al. 2011, p. 5).

2.4.3 Total Welding Management

TWM (Total Welding Management) is a quality management tool for welding production. The founder of TWM is Jack R. Barckhoff who has significant experience of welding production. Significant cost savings have been achieved as the result of the implementation of TWM. This management system is used widely from hospital equipment to ship building. TWM can be implemented on the organizations of different sized. Productivity gains have increased typically from 20 % to 50 % with TWM in welding companies. TWM concentrates on changing welding operations from a cost center to a profit center. (Barckhoff 2005, p. 1.) Following ten principles are guidelines for TWM (Barckhoff 2005, p. 30-34):

1) *Welding is a Science:* Welds are controllable within the scientific knowledge of welding parameters and process variables.
2) *Most Welders Want to do a Good work:* Most of the welders are eager to do a good job and improve their skills. Usually welders have not gotten enough training or

help for their welding problems which are caused by motivation problems. Positive feedback and support from supervisors lead to better performance.

3) *Hands-On Leadership:* The welders must be supported by the supervisors and even the top management. An organization is changed upside down. Also the responsibilities of supervisors and welders are extended and empowered. The position of inspectors has been changed from auditors to advisors.
4) *Teamwork and Goals:* Functional departments have to work together towards the best result for a company. In general every departments of the company try to optimize their own results. Superior performance can be reached by doing things which are the best for the company and welders.
5) *Functional Departments as Support:* Different departments, which are manufacturing engineering, manufacturing operations, quality assurance and design engineering, must realize the upside down organization and the importance of the supported welders. It leads to improvements in welding quality and productivity.
6) *A Plan for Change:* A boat does not turn itself. Sustainable and resistant results must be planned and organized without any compromises. The essential components must be planned for the improving sustainable performance of an organization. The components are priorities, training and resources.
7) *Methodology for Change:* A successful company has a structured methodology for changing processes systematically. It can be separated into three parts as follows:
   - Identification and quantification
   - A plan with goals
   - A detailed action plan

   If potential savings are immeasurable, organization members will not understand why the changes are required. The plan is necessary with specific measurable goals, resource requirements and time frames. The detailed action plan is a road-map what answers to the question of what, who, how, when, measurement as well as a completion is documented and agreed.
8) *A Strong Foundation:* New trainings, improved quality policies, and meaningful welding applications are built slowly and in an organized manner. Improvement projects must be identified systemically and implemented project by project. Completed projects will show benefits of TWM to everybody. Welding operations are controlled in the end.

9) *Training:* Usually the training is overlooked. New management system fails without training on all levels and functions. The welders need to have knowledge on the essential welding processes of the company. Also the management needs to practice management and technology.
10) *Ownership of Company of Welding Management System:* Every company needs their own management system what is based on the needs of unique culture, products and management. It is not the best solution to adopt a ready management system. A tailored management system focuses on the essential needs of the company.

If five major goals of TWM, so called five welding do´s, are combined with four critical functions, welding improvement opportunities will be identified and quantified. The condensed potential saving procedure of the five welding do´s and the key results areas of the four critical functions in welding production are shown in Figure 13. The matrix has 100 cells which reveal specific opportunities to improve productivity and quality. (Barckhoff 2005, p. 65, 77-78.)

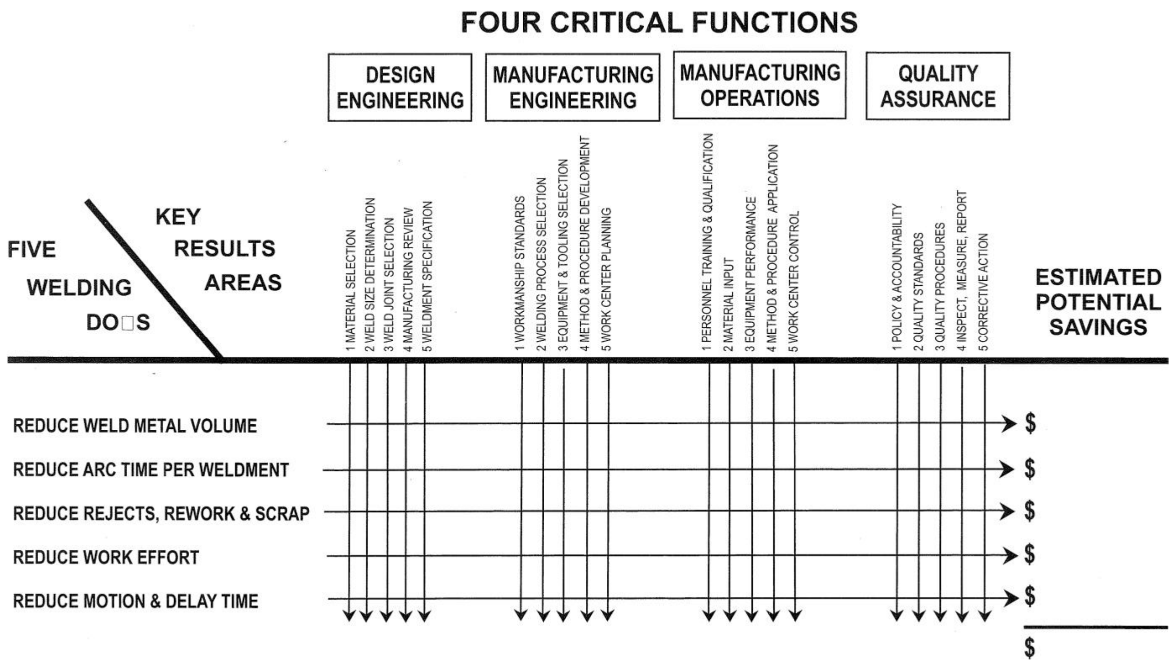

Figure 13. The potential savings from the key results areas in the welding production (Barckhoff 2005, p. 78).

2.5 Subcontracting in maritime industry

The workmanship, confidence and security of subcontractors are significant factors when suitable subcontractors are chosen in the marine industry. Usually these factors have also been seen the most important developing targets. The trust between a shipyard and customers is based on effective scheduling as well as openness and honestly in problem solving. It is important subcontractors want to develop their processes under changing operational environment. Cost efficiency and total efficiency are the important factors of price competitiveness. (Vuorenmaa & Välimaa 2015, p. 39.)

The challenges, developmental needs and requirements of subcontractors are the same for the different departments or field of operation. Quality requirements and staying on schedule are the most important developing targets of subcontractors in the machining, hull production or interior production. Unsystematic planning causes major problems in valuing resources and planning the supply chain. Previous scheduling mistakes can also cause scheduling and planning problems to subcontractors. Insufficient requirement specifications and source information also cause significant delays. Developing project management, coordination and scheduling can be a good starting point to solve the schedule problems. (Vuorenmaa & Välimaa 2015, p. 39–40.)

Orientation and training have been presented to be proposed solution for quality problems. Motivation and expertise can be improved by training, which can be organized inside the company. Only better orientation and internal training raise quality awareness. Better process handling and good planning help to achieve the required quality level. Quality can also be improved by developing quality assurance and inspection. The attitudes of workers can be inspired by motivating and stimulating. (Vuorenmaa & Välimaa 2015, p. 30.)

2.5.1 Subcontractor requirements at Meyer Turku

Subcontractors are invited to tender for each project at Meyer Turku. A goal is getting turnkey solutions from the subcontractors. A subcontractor with the best offer wins the bidding competition. The best offer is not the cheapest automatically. Price, delivery terms, credibility and flexibly are considered when the best offer is determined. The cheapest offer can cause quality cost into other production. (Vuorenmaa & Välimaa 2015, p. 13.)

The quality and delivery times of the subcontractors are investigated closely at Meyer Turku. By references the competence of a subcontractor is estimated. Audited systems are not required from the subcontractors if internal project management and quality control works otherwise. The size of the subcontractors is not defined in requirements. Usually small subcontractors are more flexible. The developing targets of the subcontractors are meeting to technical requirements of quality and having expertise in management. (Vuorenmaa & Välimaa 2015, p. 13–14.)

2.5.2 Quality assurance in welding at Meyer Turku

Own welders of Meyer Turku are hired into the hull production of the shipyard from direct recruitments or the welder plate fitter course of the shipbuilding academy of Meyer Turku. Even experienced but new welders take part to the course if it is reasonable. Probability is higher for quality variation when welding length increases. That is why the qualifications of welders do not reveal the welding skills in practice. Necessary tasks of the shipyard are practiced in the course. The tasks are for example reading drawings and WPS, storage of filler materials, flame straightening, prefabrications in the field and fixing welding defects as well as typical welding techniques. The welding techniques include the peculiarities of welding manholes, crossings and tanks which are not included in the standardized qualification test for welders. An exam is arranged from welding defects, reading WPS and the responsibilities of VT (visual inspection) for example. (Eskonen 2016.)

The professional knowledge of the subcontracted welders is inspected by the qualifications of welders. The employee turnover of the subcontractors is high which set the limits for training and checking. If problems are detected in the welding quality, the welders will be ordered to weld the new qualifications. Sometimes new subcontracted welders have been equipped insufficient. Balancing between the pressure of workload and wanted quality level is demanding sometimes. The best welders are marketable in the price competition. (Eskonen 2016.)

2.5.3 Preventing the common welding defects of subcontract welding

An imperfection is discontinuous section or deviation in the ideal weld and a defect must be repaired. The imperfections lower the durability of joints or other properties. That is why the welding production aims to cut down the imperfections. In the other hand the production costs will increase if the quality requirements are unduly tight. (Lukkari 1998, p. 32).

Theoretical reasons for the most common defects in the records of RT (Radiographic Testing) and UT (Ultrasonic Testing) of one ship are separated in table 1. The most common defects are chosen by analyzing RT- and UT-records in the results of this thesis. Parameter and welding conditions are separated into two parts. The upper section of the table considers parameters, which are measured for WPS inspections for this thesis. Lack of welding conditions and preparing works are concerned in the lower section of the table.

Current, voltage, travel speed and arc energy as well as lack of preparation work have strong relation to lack of fusion. Slag inclusion is caused by too convex beads in multi-run weld or weld pool runs ahead of the arc. Moisture, unclean groove and layers as well as insufficient preheating and gas shielding can cause porosity. Elongated cavity is caused by welding over rust or paint. Crater pipes can be avoided by grinding the ending of the weld or moving welding torch backwards from the end of the weld. Longitudinal cracks can be avoided by using lower arc energy and greater than one width/depth ratio of welding groove as well as cleaning impurities. (Lukkari 1998, p. 47–49.)

Table 1. Theoretical reasons for the most common defects in the RT- and UT-records of one ship (Modified from Lukkari, 1998 p. 47–49).

	Lack of fusion	**Slag inclusion**	**Porosity**	**Elongated cavity**	**Crater pipe**	**Longitudinal crack**
Over current (A)	x					x
Under current (A)	x	x	x	x		
Over voltage (V)	x					
Under voltage (V)	x					x
Over gas flow (l/min)			x	x		
Under gas flow (l/min)			x	x		
Over travel speed (cm/min)	x					
Under travel speed (cm/min)	x	x				x
Over heat input (kJ/mm)	x					x
Under heat input (kJ/mm)	x					
Unclean groove or layer	x	x	x	x		x
Wrong geometry of the groove	x	x				
Moisture			x	x		
Insufficient preheating			x	x		x
Wrong torch positioning	x	x				
Welding over convex beads	x	x				
Shrinkage cavity at the end of the weld is not grinded					x	

2.6 Quality Assurance tools in subcontract welding work

This chapter introduces different quality assurance tools in welding network which are linked to Internet of Things. It is introduced in Chapter 2.6.1. Real-time data monitoring is introduced in Chapter 2.6.2. Cloud-based quality and safety management is introduced in Chapter 2.6.3.

2.6.1 Internet of things (IoT)

A lot of discussion has been around IoT (Internet of Things), Big Data and analytics because their forecasted market value is 1.9 trillion dollars in 2020. If the Finnish companies are active in these markets, according to the forecast, 12 billion euro investments and 48000 new jobs can be achieved. (Yritysjohdon opas IoT:n ja teollisen internetin hyödyntämiseen 2015, p. 3.)

Based on a research of Gartner 4.9 billion devices were connected to internet in 2015 and 25 billion things will be connected in 2020. It means 5 devices per capita globally. Gartner defines IoT as physical devices which can sense environment, share information and use that information. The hierarchy of IoT is shown in Figure 14. (Yritysjohdon opas IoT:n ja teollisen internetin hyödyntämiseen 2015, p. 4.)

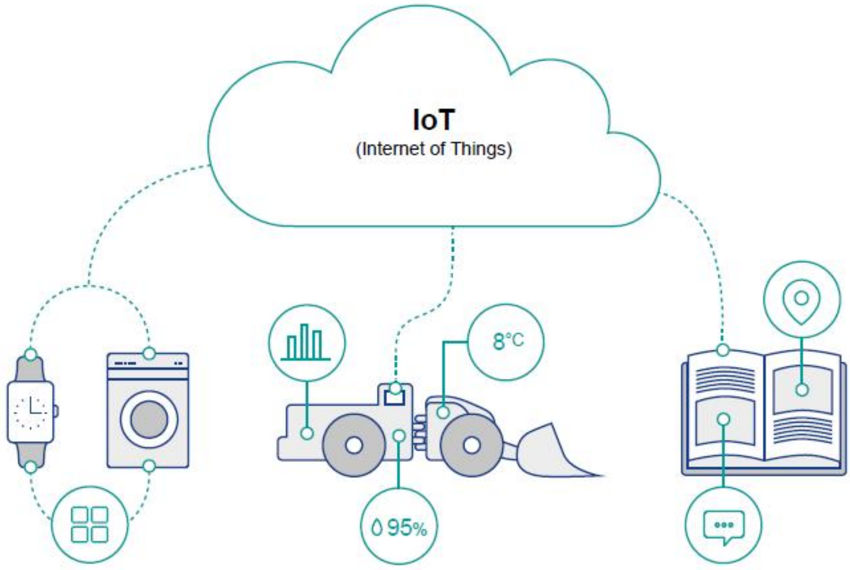

Figure 14. IoT can be separeted to connected home devices, industry devices and goods. (Yritysjohdon opas IoT:n ja teollisen internetin hyödyntämiseen 2015, p. 4).

2.6.2 Real-time data monitoring

Nowaday construction projects are bigger, requiring stricter quality standards, tighter schedules and more demanding structures besides increasing productivity needs. The WPS can be seen to be a receipt in the welding industry. Manual welding work has been inspected difficultly. Data can also be collected digitally which means that it is collected automatically. The real-time data collecting enables real-time quality control on the shop floor. Each weld can be tracked down and documented. (Controller 2016.) The different systems of Kemppi, Esab, Lincoln Electric and Fronius for welding management are compared in table 2.

Table 2. The Summary of the properties of signature image processing systems in welding networks (Kemppi 2016; Kierkels 2016; Lincoln Electric 2015, p. 17–20, 85–115; Fronius 2012, p. 8, 24, 29, 48, 50–53, 59–63).

<table>
<tr><th></th><th>Kemppi
Kas3</th><th>Esab
WeldCloud</th><th>Lincoln
Checkpoint</th><th>Fronius
Xplorer</th></tr>
<tr><td>Measurable parameters</td><td>Current, voltage, wire feed speed and duration</td><td>Current, voltage, wire feed speed and duration</td><td>Current, voltage, wire feed speed and duration</td><td>Current, voltage, wire feed speed and duration</td></tr>
<tr><td>Validity of the welders qualifications</td><td>Checkable with a bar scanner and automatic expiry notifications</td><td>The bar scanner can be added</td><td>-</td><td>-</td></tr>
<tr><td>Real-time quality control</td><td>Comparing welding actions and WPSs</td><td>Comparing value limits and welding actions</td><td>The welding actions are scored by previously saved actions</td><td>Comparing the value limits and welding actions</td></tr>
<tr><td>Production Management</td><td>An overview</td><td rowspan="2">Welding data for each weld can be exported to Excel</td><td>The overview and data can also be exported</td><td rowspan="2">Welding data for each weld can be exported to Excel</td></tr>
<tr><td>Traceability</td><td>As-built documentation</td><td>Operator identifiers, Consumable identifiers & part serial numbers</td></tr>
<tr><td>Information sharing</td><td>User profiles in the cloud</td><td>E-mails & mobile platform</td><td>The e-mails, text messages and mobile platform</td><td>User profiles in the program</td></tr>
<tr><td>Expandability</td><td>Kemppi: FastMig/M/X/ Synergic/KMS

With adapter to MIG/MAG, TIG, MMA of other manufacturers and older Kemppis</td><td>Esab: Aristo Mig 4004i Pulse/5000i/U5000i/U5 000iw/ 1000 ACDC and Origo Mig 6502 CW/ 6502 MultiV</td><td>Lincoln: Power Wave</td><td>Fronius: TS4000/5000, TPS2700/ 3200/4000/ 5000/7200/ 9000</td></tr>
<tr><td>Implementation of network</td><td>Wifi (Wireless local area network)</td><td>Wifi/3G (Third generation of mobile telecommunications technology)</td><td>Ethernet</td><td>Ethernet</td></tr>
</table>

The customized interface of a cloud based system makes it possible that the system can be used in different applications. The variations of different shop floors and role based accesses for sharing data can be created. The senior management can tap information for the asset utilization purposes in the big picture. Production and shift statistic can be investigated more closely by the production managers and supervisors. Other metrics can be analyzed for decision making by the supervisors and production management. An example the bottlenecks can be identified and long-term solutions created in a strategic field. The welding engineer and supervisors can focus on the weld quality. (Lincoln Electric 2016a.)

Different parameters can be measured by IoT systems. It is possible every weld can be sorted by wire type and the system measures usage of wire, welded metal, wire feed speed as well as deposition rate. The usage of wire types can also be tracked. In addition, when welding consumables is running out the system sends the alert message. The cloud servers guarantee that even the data from different sites can be handled. (Lincoln Electric 2016a.) The one way to monitoring data and getting notifications from the welding units through the cloud to the users is shown in Figure 15 (Lincoln Electric 2016b).

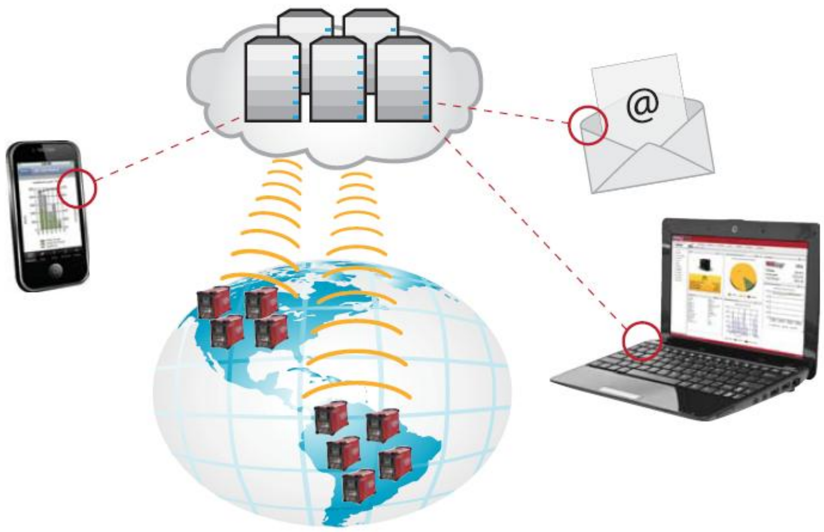

Figure 15. Notifications to the users from the welding units (Lincoln Electric 2016b).

NDT is demanded in the welding production. But it does not guarantee that every weld has been welded in accordance with WPS. It also is an important factor concentrating on used working methods and the qualifications of welders. For example, the IoT system of Kemppi can check following standard based requirements (Jernström 2012, p. 14.):

- The welder is qualified
- WPS is followed
- Maintenance of welding equipment is planned
- Welds are traceable.

Reliable tools are one of the most important things for the quality. The reliable working provides every step can be made without harms in the production. The specific information of welding units can be collected by the IoT systems. Every maintenance work will be saved and the system informs the maintenance needs if problems are detected in wire feeding or operating hours are near the end. The wire feed problem can cause the welding defects and that is why real time information is important. (Jernström 2012, p. 15–16.)

Some IoT systems can handle the collected information and put the information together as well as create quality documentation. The identifications of a welder, WPSs, numbers of the consumables can be collected by bar codes. Every welding action has a timestamp so it is possible to know when mistakes are happened. The time-consuming quality document collecting is costly so the savings can be achieved by the partly automated system. For example, collecting the welding documentation can be bottleneck in the offshore industry. (Jernström 2012, p. 15.)

2.6.3 Cloud-based safety and quality management

A paper documenting is a familiar way to carry out document management as introduced in Figure 16. For example, paper document must be printed out that measurements and inspections can be written down. Therefore the paper documents must be written clean and save into the data system of a company. In addition every photo and other attachments are attached separately. The paper documents will not remind if repairs are not performed. (Congrid 2016).

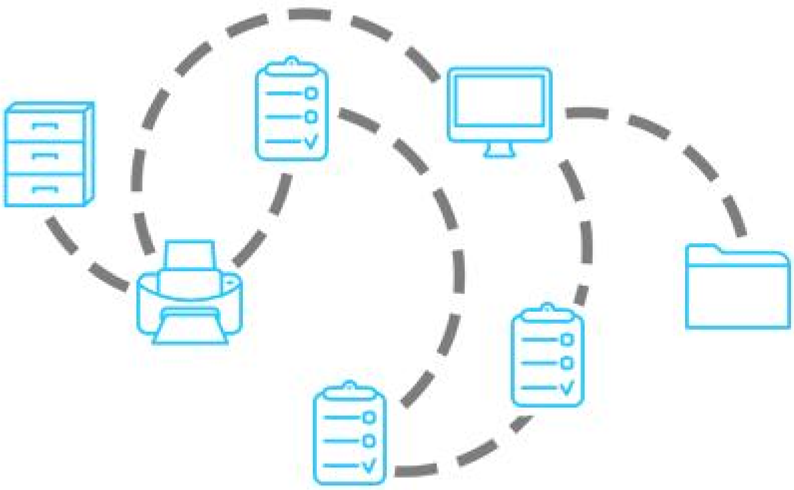

Figure 16. A manual documenting (Congrid, 2016).

Production management can be performed differently with a cloud based documenting what is shown in Figure 17. Documents are available from the cloud and quality can be inspected immediately. A program make, save and share reports instead of an inspector doing it. The repairing of defects can be followed in real time.

Figure 17. A cloud based documenting (Congrid 2016).

2.7 Statistics

Statistics can be defined as collecting, analyzing and drawing conclusion from data. The process of statistic starts from identifying a question. Next relevant data is collected on the topic which will be analyzed. The last part of statistics infers the analyzed data. (Diez, Barr & Cetinkaya-Rundel 2015, p. 6.)

The variables of statistics can be separated in numerical and categorical variables as shown in Figure 18. Variables will be numerical if they can take a wide variety of numerical values. Variables will be continuous if they are federal spending. If numbers can only take whole non-negative number, they will be discrete. Ordinal categorical variables describe the levels of population. (Diez et al. 2015, p. 12.)

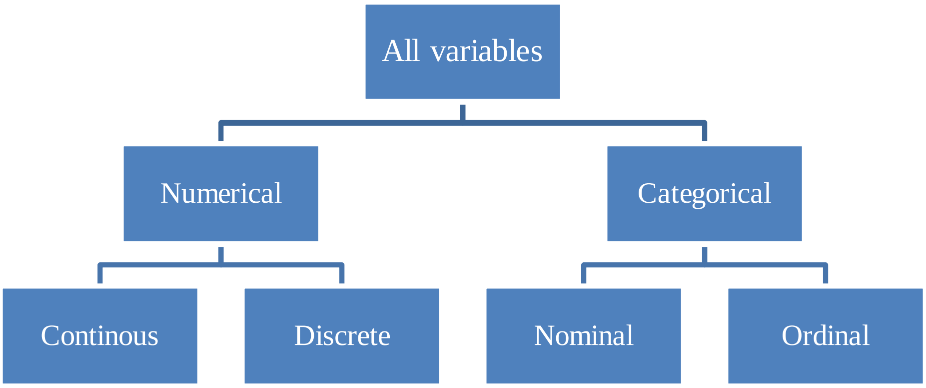

Figure 18. The variables of statistic (Modified from: Diez et al. 2015, p. 12).

2.7.1 Randomizing

If all possible observations in a population are collected, the research will often be expensive. That is why a sample is collected. The sample represents a small fraction of population. The small fraction estimates variables in the entire population. A large amount of data can be summarized into a single number by a summary statistic. (Diez et al. 2015, p. 9, 15.)

A bias is problematic for a sample. With raffling the bias can be minimized. A convenience sample is a common problem in the random sampling because other individuals are easier accessible and they will be chosen into the sample as shown in Figure 19. These sampled sub-populations are not easy to discern from the sample. (Diez et al. 2015, p. 16.)

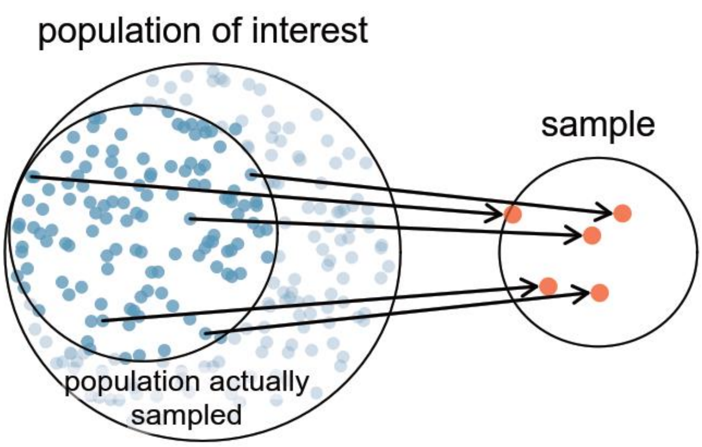

Figure 19. Actually sampled sub-population (Diez et al. 2015, p. 18).

2.7.2 Examining numerical and categorical data

Numerical and categorical data can be analyzed. Categorical variables can be presented as the sums of categorical variables in contingency table. It uses row and columns for examining relations. Data can be described by counts or proportions visually in bar plots. The bar plot with counts has more information but the bar plot with proportions presents the information more clearly. Well known and commonly used pie charts do not describe data groups as good as the bar plots because differences between groups are hard to identify. (Diez et al. 2015, p. 43–44, 46, 48).

Numerical variables can be represented in different ways than categorical data. Data can be represented as statistical key figures or graphs. Usually these are connected together. A scatterplot examines relation between two variables. If the data is diffused, there is no relation. A dot plot shows each observation and these exact values. A histogram can be plotted as bars from binned counts. They are sums of observation in allocated boundaries. Data density and its changes can be seen from the histogram. A box plot can be used for summarizing data. (Diez et al. 2015, p. 26–30, 35).

3 MATERIALS AND METHODS

In this chapter research and analysis methods are introduced. The methods are divided into interviews and statistical sections. The statistical methods were used for researching NDT and qualification mistake -records as well as the data of WPS inspections.

3.1 Interviews

The departments of Meyer Turku were unstructured interviewed for revealing the quality processes of purchasing subcontractors. The interviewed departments were procurement, QC and production departments. The welding engineer of a parental company was unstructured interviewed for getting developing ideas from their quality process.

Subcontractors were semi-structured interviewed for revealing their opinions and developing qualifications management process. The questions are as follows

1. Have you had access to the work instructions of Meyer Turku?
2. Have you had access to the programs of Meyer Turku?
3. Have you used WPSs?
4. Where are your welders qualified?
5. How quality requirements are informed?
6. Has your quality system been certified?
7. Are you ready to update prolongations into a web based qualification register?

3.2 Equipment

This chapter introduces equipment which was used for the WPS inspections and examining numerical data. A clamp meter was used for measuring voltage as well as average of current. Travel speed was measured by a yardstick and stopwatch. A rotameter tube was used for measuring the flow of gas.

The used clamp meter was Hioki 3285. The current measurement specification of the clamp meter is shown in table 3 and the voltage measurement specification is shown in table 4. The average values came from the averages of recorded minimum and maximum values.

Table 3. DC current measurement specification for mean value when temperature is 23 °C ± 5 °C and humidity is 80 % or less (Hioki 2015, p. 43).

Range	Accuracy Range	Resolution	Error
200 A	(± 10.0~ ± 200.0 A)	0.1 A	± (1.3 % + 3)
2000 A	(± 100~ ± 2000 A)	1 A	± (1.3 % + 3)

Table 4. DC voltage measurement specification for mean value when temperature is 23 °C ± 5 °C and humidity is 80 % or less (Hioki 2015, p. 45, 48).

Range	Accuracy Range	Resolution	Error
30 V	(± 3.00~ ± 30.00 V)	0.01 V	± (1.0 % + 3)
300 V	(± 30.0~ ± 300.0 V)	0.1 V	± (1.0 % + 3)
600 V	(± 60.0~ ± 600 V)	1 V	± (1.0 % + 3)

A 0.2 m yardstick was used for making the measurement process easier. Welding distance was marked with chalk beside a groove so that a welder knew the minimum distance which had to be welded. Welding time was measured by a stopwatch.

The flow of gas can be measured by a rotameter tube that is shown in Figure 20. If fixed pressure of a gas distribution system is used, the flow of gas will be set by a wire feeder. The types of gas define which scale of the rotameter is used for measuring. The same rotameter can be used for argon and mixtures with acceptable accuracy because the gas properties of argon, carbon dioxide and oxygen are similar. (Weman & Linden 2006, p. 67.)

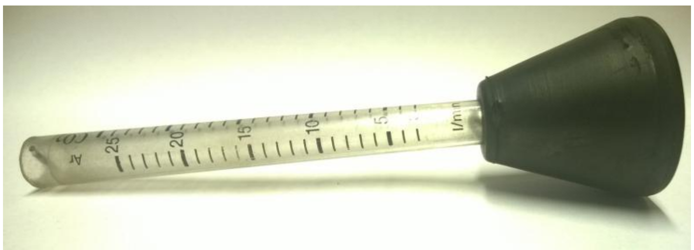

Figure 20. A rotameter tube for measuring flow of gas.

Microsoft Excel 2010 is the most popular spreadsheet tool today. The Data Analysis tool of Excel can be used for computing results. (Salkind 2016.) The features of Excel were used for analyzing the data of this thesis.

3.3 Quality field logs

This chapter introduces NDT and qualification shortcoming -records. NDT records are collected according to instructions of Meyer Turku. All inspections must be reported systematically. Additional inspections will be taken if defects continue outside of inspection areas. (Nondestructive inspection plan of hull construction 2014, p. 2.)

Ultrasonic testing is used for the full penetration butt welds. Planned ultrasonic inspection length is longer in middle of the ship, which is the most critical point in terms of strength. The ultrasonic testing is also used for process controlling and other specific targets. (Nondestructive inspection plan of hull construction 2014, p. 6–7.) An example of UT-record is presented in appendix III.

Radiographic testing is used for section borders and the internal targets of grand blocks. More films are taken in the middle of the ship. Inspection targets are defined to inspection drawings. (Nondestructive inspection plan of hull construction 2014, p. 4–5.) An example of RT-record is presented in appendix IV.

Welder qualification problems are collected in a qualification mistake records every week. Problems are separated into six different problems. Also the information of how long the welder has been on the list is collected. The construction of the record and the six problems are presented in appendix V.

3.4 An experimental arrangement for measuring welding parameters

This chapter introduces procedure to perform WPS inspection. The selecting of welders is introduced for WPS inspection. Also the method of parameter measurement is introduced in this chapter. The results of WPS inspections were compared to WPSs of Meyer Turku.

An inspector has chosen welders randomly in production halls during inspection. The halls of production phases and their conditions are as follows

1) 4H: A warm hall where partly outfitted units are assembled
2) 6H: A warm hall where blocks are assembled
3) 8H: A warm hall where partly outfitted units are assembled
4) K1: A cold hall where grand blocks and blocks are assembled

5) K2: A cold hall where grand blocks and blocks are assembled
6) K3: A cold hall where blocks are assembled
7) SK: A cold hall where blocks are assembled
8) Dry dock: An outside area where the hull is assembled
9) Outside: Other outside areas where grand blocks are assembled

The results of voltage measuring depends notably where the connections are set. Voltage error will be remarkable if measurements are not performed close to the arc. The cables of the meter should be set near the arc on the work piece and on the drive rolls of the wire feeder. Even so the voltage of the arc is lower than the voltage of power source terminals depending on the resistance of cables and the amplitude of the welding current. (TWI 2016). Voltage measuring technique for the WPS inspection is shown in Figure 21.

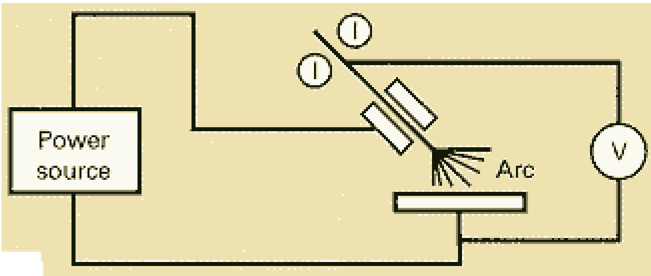

Figure 21. Voltage measuring technique for the WPS inspection (TWI 2016).

The current is the same at any point of the circuit, it can be measured at the circuit. Direct current can be measured with a clamp meter even if it is sensitive for errors and some of the clamp meters are not exact. (Lukkari 1998, p. 76.) Current measuring technique for the WPS inspection is shown in Figure 22.

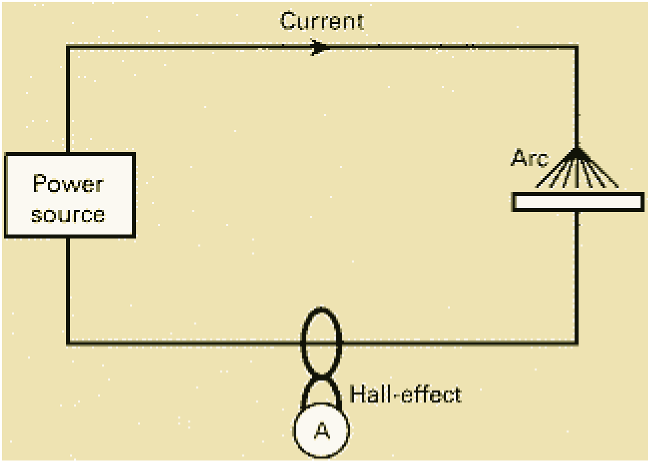

Figure 22. Current measuring technique for the WPS inspection (TWI 2016).

The flow of gas was measured by the rotameter. The rotameter was set on a torch when wire feed was switched off. The gas flew through a rotameter tube and the flow of gas was able to be read from a scale.

Travel speed is calculated as average velocity. Therefore travel speed can be defined as

$$\bar{v} = \frac{\Delta x}{\Delta t} \tag{2}$$

, where $\bar{v}$ is average velocity, Δx is displacement and Δt is time period which are defined by the yardstick and stopwatch.

Arc energy E is the used energy for each run per length unit. The arc energy is used because it is used in the WPSs of Meyer Turku instead of the heat input. The arc energy E can be defined as

$$E = \frac{A*V*t}{s_w} \tag{3}$$

, where A is current, V is voltage, t is time and s_w is the length of a weld run. (Lukkari 1998, p. 54.)

3.5 Statistical experiments

The data of this thesis was separated into numerical and categorical variables. Welding in accordance with WPS is a nominal variable. The length of imperfections and defects as well as the percent exceedances of WPSs are continuous variables. Welding defect and imperfection types are ordinal variables. Discrete variables are the weekly quantities of qualification mistakes.

The frequency of the welding defects of the subcontractors was computed from the field logs of the UT- and RT-inspections. From these field logs the statistical key figures of defects and inspection lengths were collected for analyzing. The box plots were created for defects and inspection lengths.

The statistic key figures of WPS inspections to subcontractors were counted. The histogram of the WPS inspection was created. Also the statistical key figures and box plots of qualification mistake records were collected. The production halls and subcontractors were compared by the relative frequency of not welding in accordance with WPSs.

3.5.1 Statistical key figures

Minimum is the lowest value and maximum is the greatest value of observations. The minimum and maximum can be used for determining obvious outliers or skew. Median is the value what splits observations in half in the middle. If a sum of the observations is even, the median is the average of the midst numbers. (Diez et al. 2015, p. 35–36, 227).

The center of the deviation of sampled data can be measured by a sample mean what can be computed as

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad (4)$$

, where $\bar{x}$ is the sample mean and N is observations for of x_i variable. (Diez et al. 2015, p. 29).

The sample variance is the average of squared observations from the sample mean. The standard deviation is the square root of the variation. Spreading out of the observations is measured by the standard deviation. The sample variance is equal to

$$s^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2 \tag{5}$$

, where s^2 is variance, N is observations for of x_i variable and $\bar{x}$ is the sample mean. The sample standard deviation is defined as

$$s = \sqrt{s^2} \tag{6}$$

, where s is the sample standard deviation and s^2 is variance. (Diez et al. 2015, p. 33.)

The typical error of the point estimate can be described by the standard error of the sample mean. The standard error of the sample mean is equal to

$$SE = \frac{\sigma}{\sqrt{n}} \tag{7}$$

, where *SE* is the standard error of the sample mean, n is independent observations and σ is standard deviation of the individual observations what is calculated as in equation 6. (Diez et al. 2015, p. 172–173.)

3.5.2 A box plot

A box plot is shown in Figure 23. It summarizes and plots a sampled data using five statistics. A median splits the data in half. IQR (Interquartile range) describe variability of data. Data outside the IQR area is captured by whiskers.

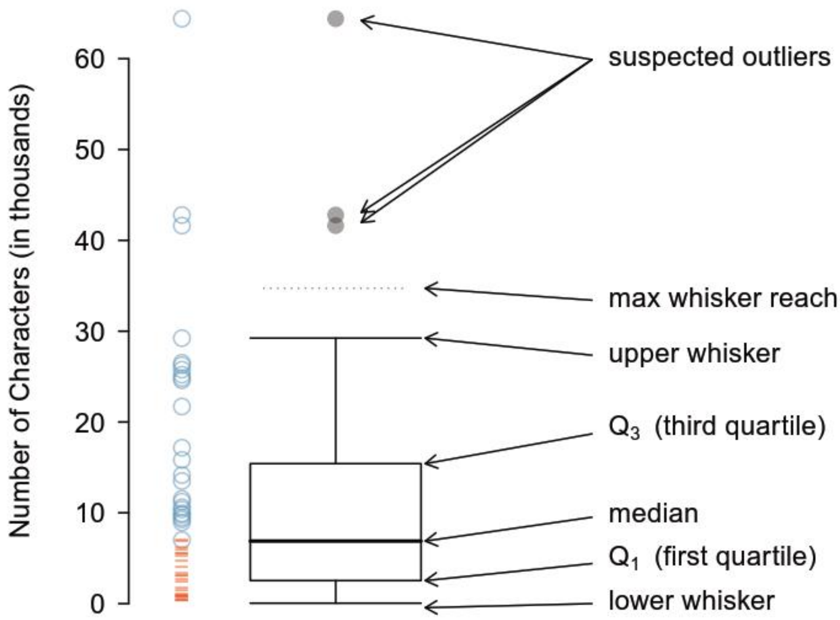

Figure 23. A box plot for summarizing a data (Diez et al. 2015, p. 35).

The IQR represents the middle 50% of the sampled data. The IQR measures variability in the data. The first quartile is 25th percentile below a median and the third quartile is 25th percentile over the median. The range of the *IQR* can be defined as

$$IQR = Q_3 - Q_1 \tag{8}$$

, where *IQR* is interquartile range, Q_3 is third quartile and Q_1 is first quartile. (Diez et al. 2015, p. 36.)

The whiskers capture a data outside of the IQR area. Unusual observations can be identified by the whiskers. The greatest value wherein the whisker can be defined as

$$w_{max} = Q_3 + 1{,}5 * IQR \tag{9}$$

, where w_{max} is the most up whisker, Q_3 is third quartile and *IQR* is interquartile range. The lowest whisker is equal to

$$w_{min} = Q_1 - 1{,}5 * IQR \tag{10}$$

, where w_{min} is the lowest whisker, Q_1 is third quartile and IQR is interquartile range. (Diez et al. 2015, p. 35.)

3.5.3 A histogram and normal distribution

Instead of plotting each observation, these can be allocated by bins which are defined between defined values. A histogram is formed by the sum of the bins. Data density and its shape can be described by the histogram. (Diez et al. 2015, p. 30.)

A normal distribution is the most common of distributions which are introduced as upper curves in Figure 24**.** A curve of the normal distribution can be adjusted by sampled mean and standard deviation. These parameters move, stretch and constrict the curve. (Diez et al. 2015, p. 128.)

By a normal distribution the sampled data can be analyzed and approximated. Normality of the distribution can be estimated by two visual methods which are shown in the Figure 24**.** The best fitting normal curve can be fitted overlaid on the plot using sampled mean and the sampled standard deviation. The normal distribution will be used more confidently if the curve fits the histogram better. Also the normal distribution can be evaluated by a normal probability plot. The normal distribution is representative when points fit to a perfect straight line. (Diez et al. 2015, p. 137.)

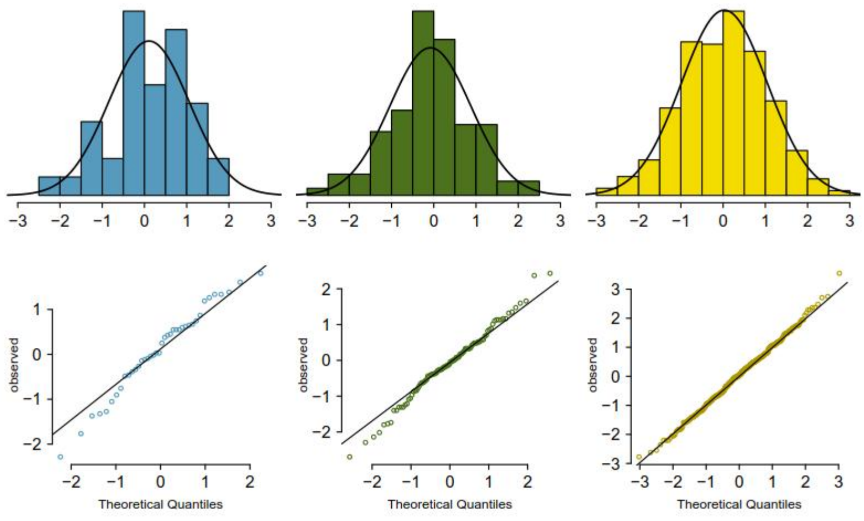

Figure 24. Evaluating the normal approximation with 40, 100 and 400 data points from left to right. (Diez et al. 2015, p. 138.)

4 RESULTS AND ANALYSIS

The results were analyzed using frequencies, statistical key figures and a histogram as well as box plots. Also the answers of interviews were analyzed for developing the qualification processes. This chapter is divided to analyze the results of welding defects, qualification procedure problems and welding in accordance with WPS.

4.1 Welding defects in UT and RT -records.

The frequencies and lengths of defects were collected and analyzed from UT- and RT-records. Additional inspections were removed from RT-records for decreasing distortion in the results. UT-inspections were used to search welding defects. Therefore the additional inspections were not separated in the UT-records. Frequencies were used to compare the types of welding defects. Statistical key figures and box plots were exploited to compare the lengths of the defects.

4.1.1 The frequencies of welding defects

The frequency of the welding defects of subcontractors, which are detected from RT-record, is shown in Figure 25. Slag inclusions occurred in 34 % of the defects found. Crater pipes occurred in 15 % and gas pores in 14 % of the defects found. Both the longitudinal cracks and the elongated cavities occurred in 7 % of the found defects. Previous defects comprise 76 % of all defects in RT-records.

The current exceedances of WPSs were possible reasons for slag inclusion, gas pores and longitudinal cracks. Insufficient voltage can have caused longitudinal cracks. Elongated cavities and gas pores can be caused by the gas flow exceedances of WPSs. Insufficient travel speed and excessive arc energy can cause slag inclusion and longitudinal cracks. Impurities can cause slag inclusions, porosities, elongated cavities and longitudinal cracks. Excessively wide grooves and welding over convex beads as well as wrong torch positioning can cause slag inclusions. Moisture and insufficient preheating can cause porosities and elongated cavities. Crater pipes are caused by shrinkage cavity at the end which is caused by not grinding the end of a weld or wrong stopping technique. All of the mentioned defects, except crater pipes, can be caused either the WPS exceedances or wrong welding techniques including prefabrications.

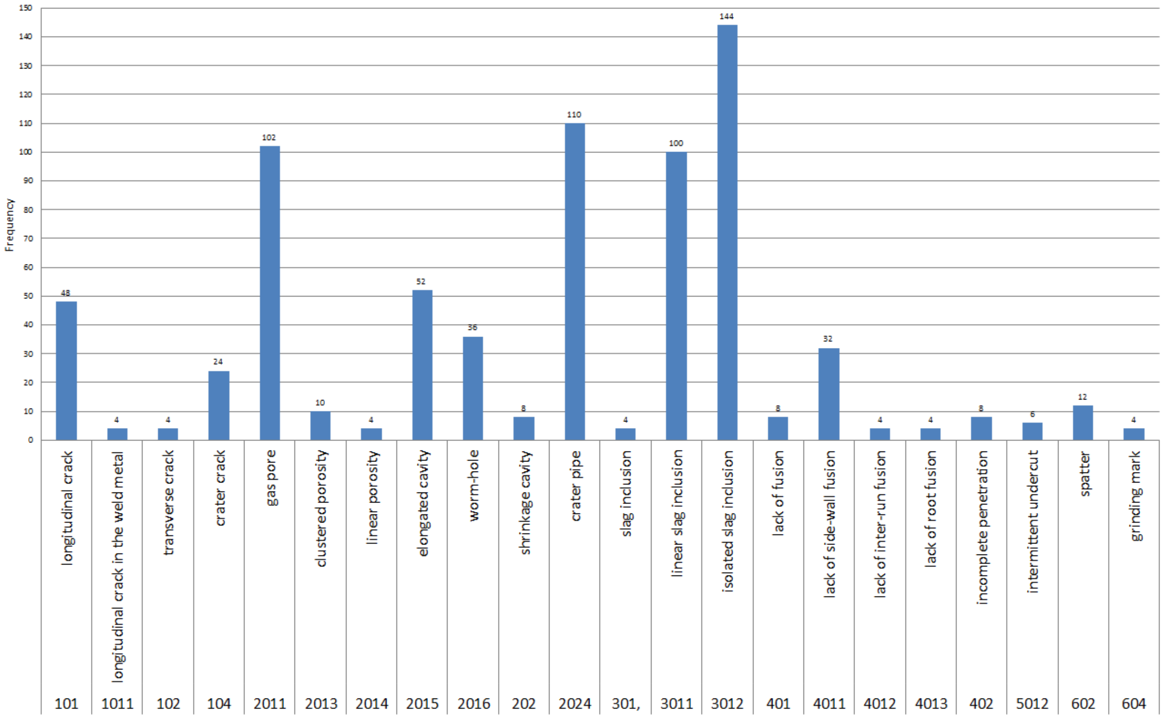

Figure 25. The frequency of welding defects in RT-record.

Moreover the frequency of welding defects, which were detected from UT-record, is shown in Figure 26. Lack of fusion occurred in 83 % and linear slag inclusions occurred in 15 % of the defects found. Previous defects comprise 98 % of the defects found in UT-records.

Lack of fusion can be caused by the current, voltage, travel speed and arc energy exceedances of WPSs as well as welding over convex beads and wrong torch positioning. Also unclean grooves or its undesired geometry are the possible reasons of lack of fusion.

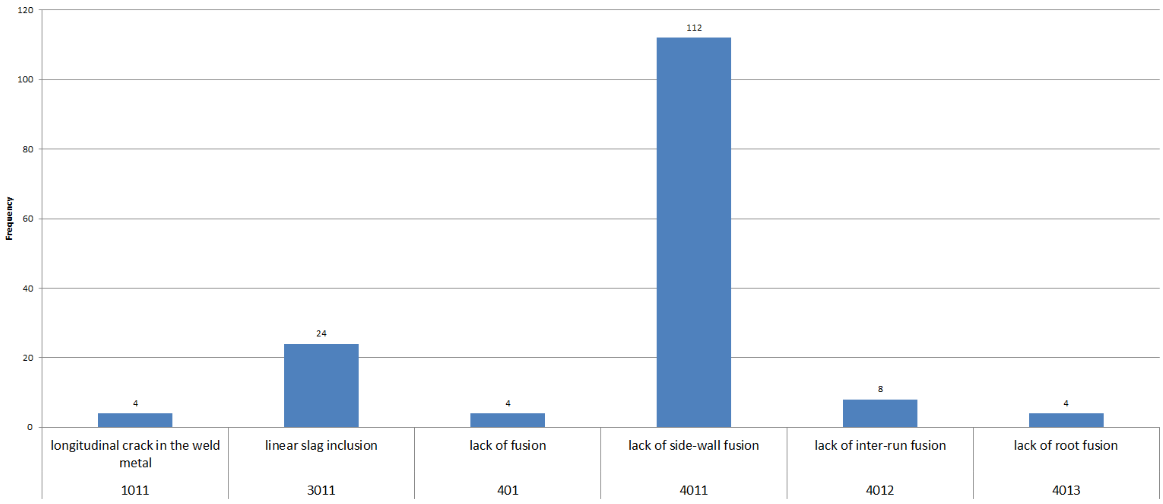

Figure 26. The frequency of welding defects in UT-record.

4.1.2 The statistical key figures of welding defect lengths

The statistical key figures of inspection and defect lengths in RT-record were calculated into table 5 using equations 4, 5, 6 and 7. The extreme values point out variation between the inspection and defect lengths. The variation of inspection lengths can be caused by more than two plates or a shorter work piece than the film. The sample means and standard deviations show that inspection lengths have usually covered welding defects. The standard error of the sample mean of defect lengths is greater because the dispersion of defect lengths is greater.

Table 5. The statistical key figures for inspection and defect lengths in RT-record.

	Inspection length [mm]	**Defect length [mm]**
Min value	220	5
Max value	560	480
Sample mean	490	163
Sample Variance	1846	26176
Sample Standard Deviation	43	162
The standard error of sample mean	3	12

The statistical key figures of inspection and defect lengths in UT-record were calculated into table 6 using equations 4, 5, 6 and 7. The extreme values do not point out variation between the inspection and defect lengths. Also the sample means and standard deviations indicate that the lengths of welding defects are near inspection lengths. The standard errors of the sample means are close together because the dispersions also are close.

Table 6. The statistical key figures for inspection and defect lengths in UT-record.

	Inspection length [mm]	Defects length [mm]
Min value	100	50
Max value	20000	20000
Sample mean	5785	4657
Sample Variance	36342225	42877202
Sample Standard Deviation	6028	6548
The standard error of sample mean	666	723

4.1.3 The box plots of welding defect lengths

The box plot representation of inspection and defect lengths obtained from RT-record is shown in Figure 27. The box plot is shorter for the inspection lengths than the defect lengths which indicate the inspection lengths have covered the defect lengths. The lower IQR and whiskers of the inspection lengths indicate the deviation is narrower for the inspection length than the defect lengths. The upper whisker of the defect lengths is slightly higher than the median of the inspection lengths which is why the inspection lengths do not cover the defect lengths has a low probability. Deviations are wider above the medians because quartile groups above the medians are wider than quartile group below the medians. The deviation of the defect lengths is narrower below than above median which is why probability of shorter defects is higher. These support the results of the statistical key figures of RT-records.

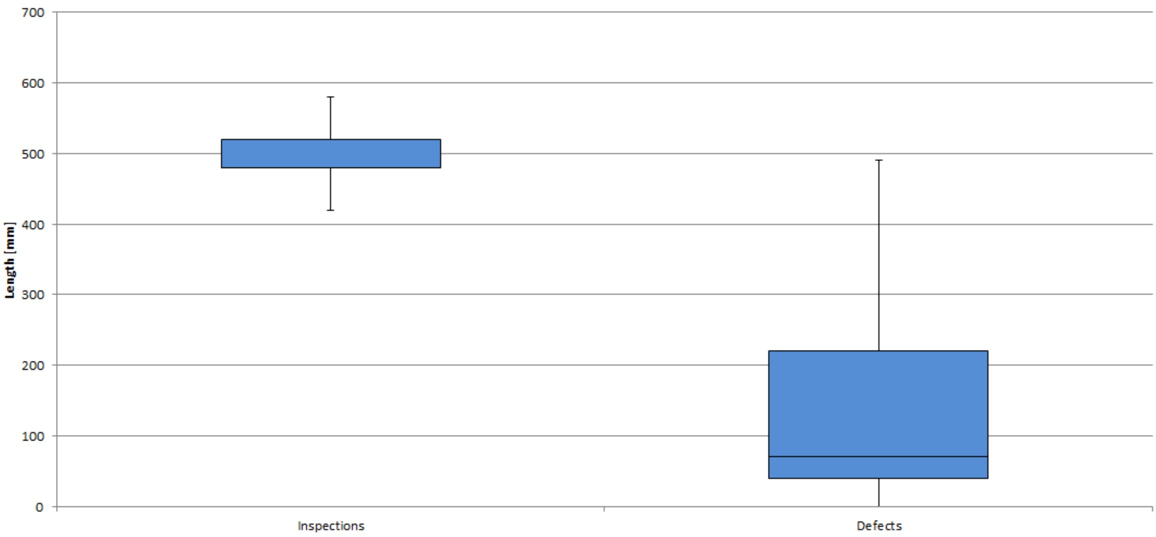

Figure 27. The box plot representation of results obtained from the inspection and defect lengths in RT-record.

The box plot representation of inspection and defect lengths obtained from UT-record is shown in Figure 28. The box plots of inspection and defect lengths are almost side by side which indicate the inspection lengths are often continued for covering the defect lengths. Also IQR of lengths indicate the deviation is almost same. Deviations are wider above than below the medians because quartile groups above the medians are wider than quartile group below the medians. The deviation of the defect lengths is narrower below than above median which is why probability of shorter defects is higher. These support the results of the statistical key figures of UT-records.

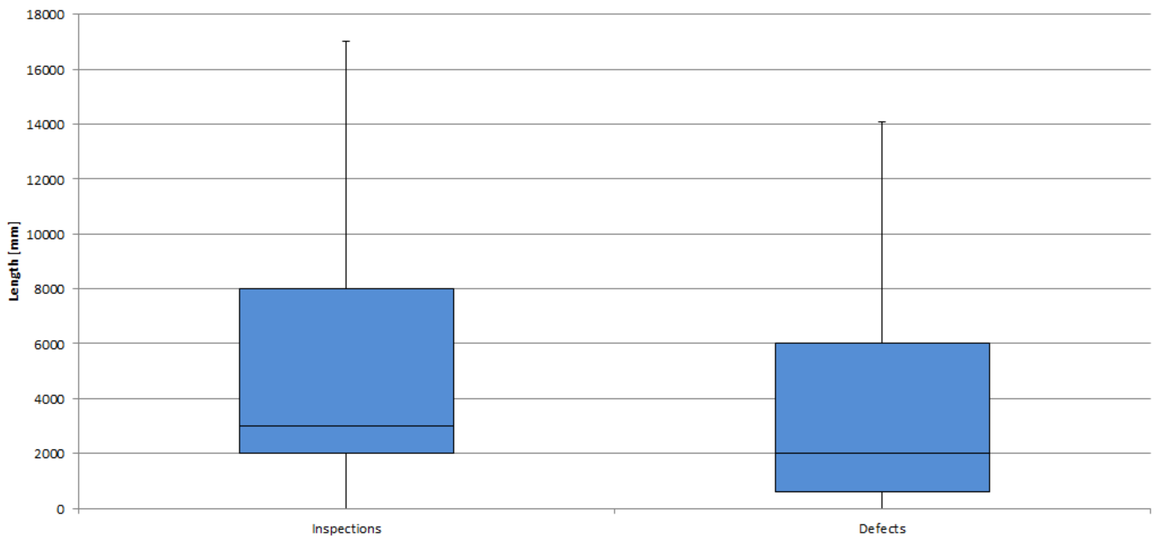

Figure 28. The box plot representation of results obtained from the inspection and defect lengths in UT-record.

4.2 Welding in accordance with WPS

The results of WPS inspections are presented in this chapter. Relative frequency, statistical key figures and graphic representation were used to analyze data. Welding out the limit of WPSs was calculated to analyze differences in parameters, subcontractors and production halls. Equations 2 and 3 were used for calculating travel speed and arc energy. The percentual exceedances of the limit values of WPSs are presented by the statistical key figures and histogram.

4.2.1 Relative frequency

The relative frequency of the measurements of the parameters and their combinations which were not in accordance with WPS are shown in Figure 29. Also the standard errors of sample mean are defined by error bars. It is more common to use lower values than higher values than in the WPSs for current, voltage and travel speed. For gas flow and arc energy it is more common use higher values than the WPSs states.

Excessive gas flow and arc energy as well as lower travel speed have the highest relative frequencies and that is the reason why these were analyzed. The excessive gas flow can cause porosity and elongated cavity, which were present in 21 % of all defects found in the RT-records. High arc energy can cause lack of fusion and longitudinal cracks. The lack of fusion covered 83 % of the defects found in the UT-records and longitudinal cracks occurred in 7 % of all defects found in RT-records. Insufficient travel speed was connected to high arc energy causing also slag inclusions which occured in 34 % of the defects found.

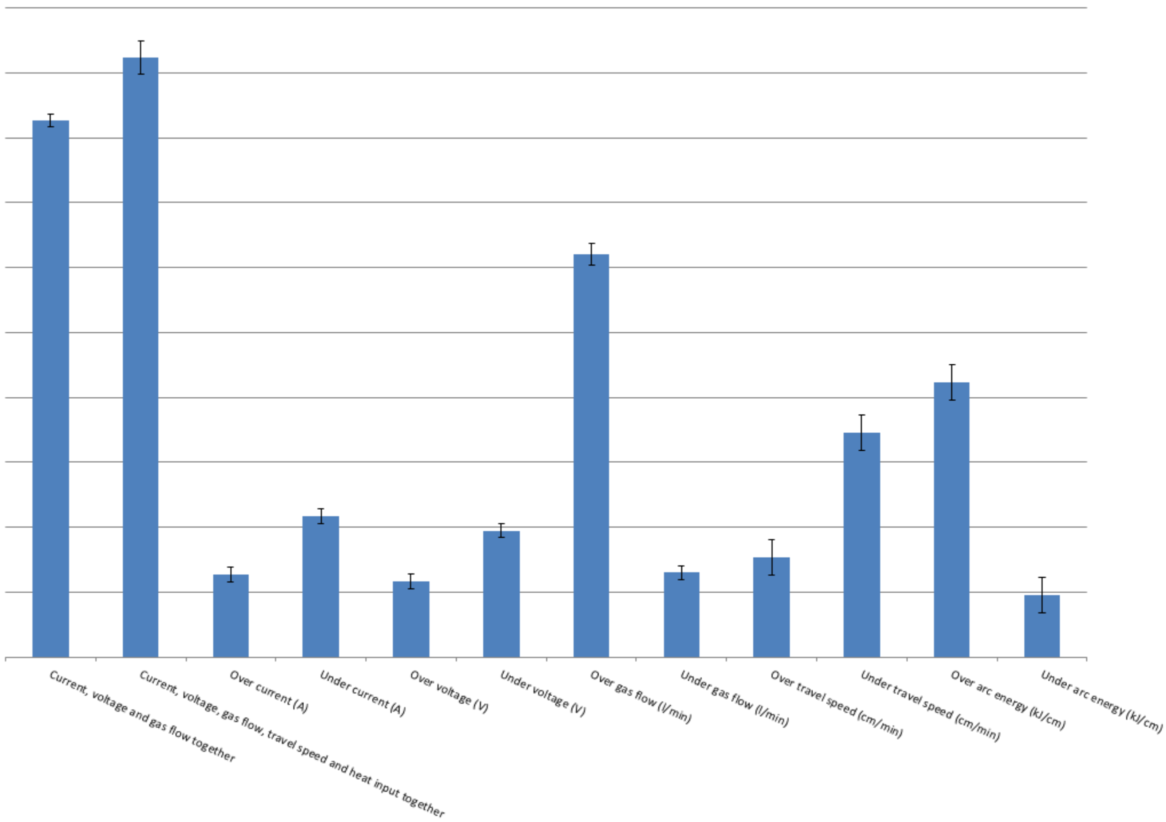

Figure 29. The relative frequency of the measurements of the parameters which were not in accordance with WPS.

The relative frequencies of the WPS measurements of main subcontractors which were not in accordance with WPSs are shown in Figure 30. The subcontractors were Subcontractor A, D, E, F, J and N. A comparison was only analyzed for current, voltage, gas flow and their combinations together because the quantity of the measurements of travel speed and arc energy were not sufficient. The gas flow was the most common reason why welding was not within the range of WPS parameters. For example Subcontractor J will be performed the worst if the current and voltage exceedances of WPSs are the criteria. If same criteria are used, Subcontractor N will be performed the best. The highest possibility to find defects was for the welds of Subcontractor J if the criteria were the relative frequency of welding current and voltage. Therefore the welds of Subcontractor D had the highest possibility for porosity and elongated cavity and Subcontractor F had the lowest.

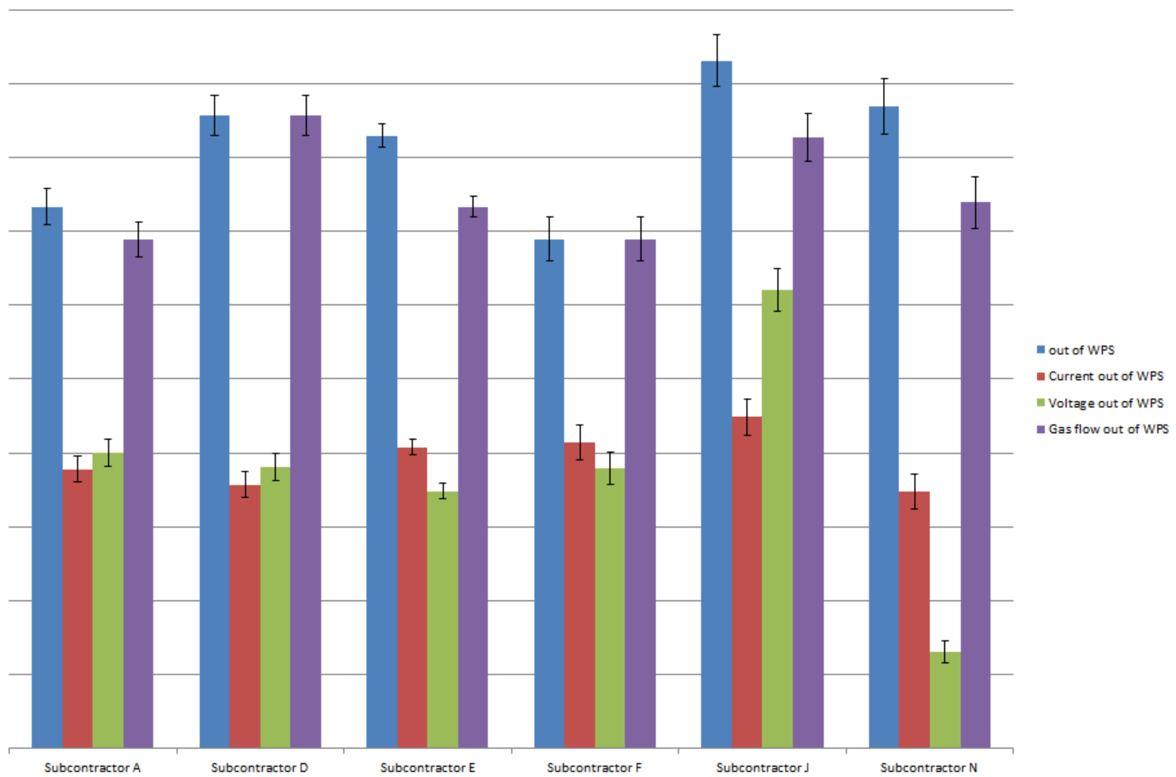

Figure 30. The relative frequencies of the measurements of main subcontractors which were not inside the limits of WPSs.

The relative frequencies of the WPS measurements of main subcontractors in production halls which were not in accordance with WPSs are shown in Figure 31. A comparison was only analyzed for current, voltage, gas flow and their combinations together. Validity would have not been reliable if a small quantity of travel speed and arc energy had been compared. The gas flow was the most common reason why welding was not in accordance with WPS parameters. Production hall K3 would be performed the worst if the current and voltage exceedances of WPSs were the criteria. K3-hall had the highest risk for finding defects, if criteria were the relative frequency of current and voltage. 8H had the lowest risk by the relative frequency of voltage exceedances. 4H had the lowest risk by the relative frequency of current exceedances. Production areas in the open air had the highest relative frequency of gas flow exceedances.

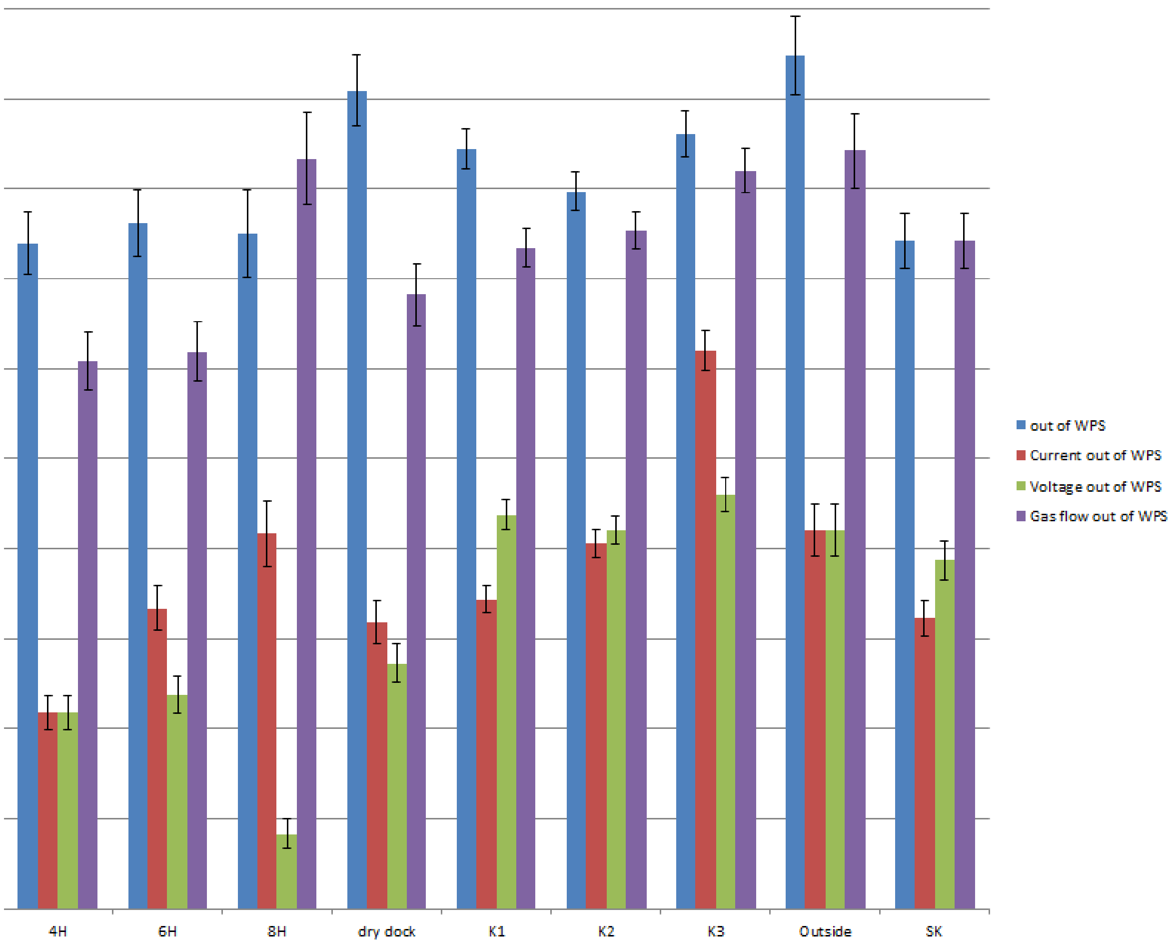

Figure 31. The relative frequencies of the WPS measurements of different subcontractors which are out the WPS in the most measured production areas.

4.2.2 The statistical key figures of the percent exceedances of WPS

The statistical key figures of the exceedances of WPS are presented in table 7. Results were calculated using equations 4, 5, 6 and 7. Arc energy is the most problematic. In the addition arc energy measures the relation of current, voltage and travel speed. Sample means and sample standard deviations are the lowest for current and voltage. The risks would be not so obvious for the typical defects of percent exceedances than risks caused by travel speed and arc energy if they were sort by the percent exceedances.

Table 7. The statistical key figures of the percent exceedances of WPS.

	Current	Voltage	Gas flow	Travel speed	Arc energy
Min	-32.6 %	-20.0 %	-93.3 %	-64.3 %	-31.5 %
Max	38.2 %	26.2 %	50.0 %	55.9 %	157.4 %
Sample mean	-1.3 %	-0.8 %	1.6 %	-6.6 %	19.8 %
Sample variance	1.4 %	0.5 %	9.2 %	7.6 %	14 %
Sample standard deviation	12.0 %	6.9 %	30.3 %	27.6 %	37.6 %
Standard error of the sample mean	1.2 %	0.7 %	2.7 %	5.4 %	7.2 %

4.2.3 The histogram of the percent exceedances of WPS

The histograms of the percent exceedances of voltage, current and gas flow are presented in Figure 32. Distributions are too kurtosis for normal distribution. Still the relation to the statistical key figures can be seen. The distributions of voltage and current are on slightly left as in the statistical key figures. Gas flow is on the right and it has outliners. Due to the outliners the sample mean of gas flow seems to be at a different position in histogram than it is in the statistical key figures. The histogram shows that the welders have anticipated windiness by higher gas flow as specified by the WPS. If a curve had been fitted over histogram, it would have been possible to define the relative frequency of welders who had parameters over defined limit value.

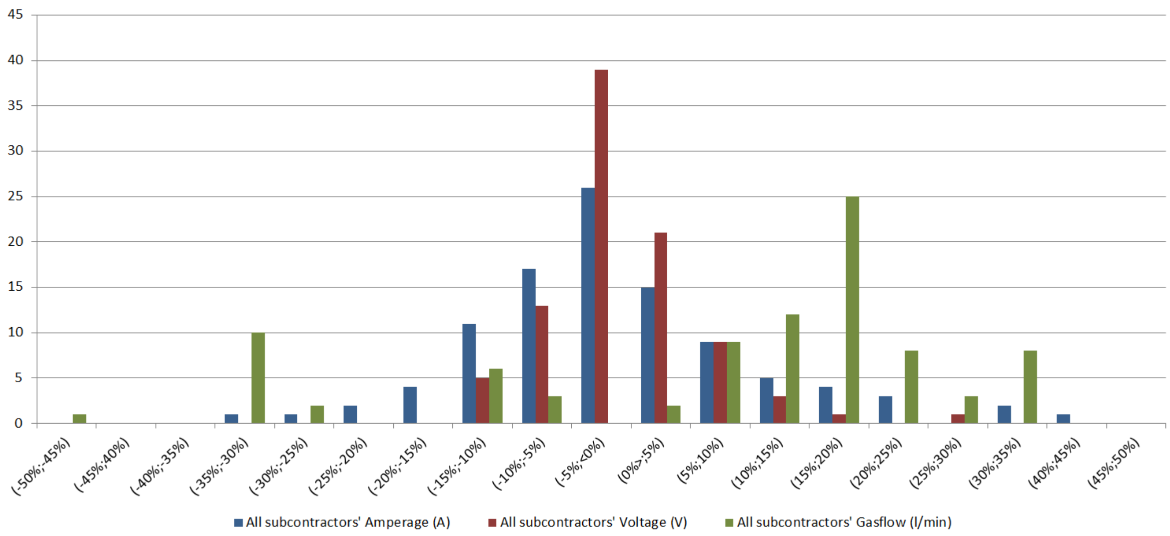

Figure 32. The histogram of the percent exceedances of voltage, current and gas flow.

The histogram of the percent exceedances of travel speed and arc energy are presented in Figure 33. Travel speed and arc energy have only 26 and 27 observations, which can be noted in table 7, the curve of deviation is not clear. That is why it cannot be used for analyzing.

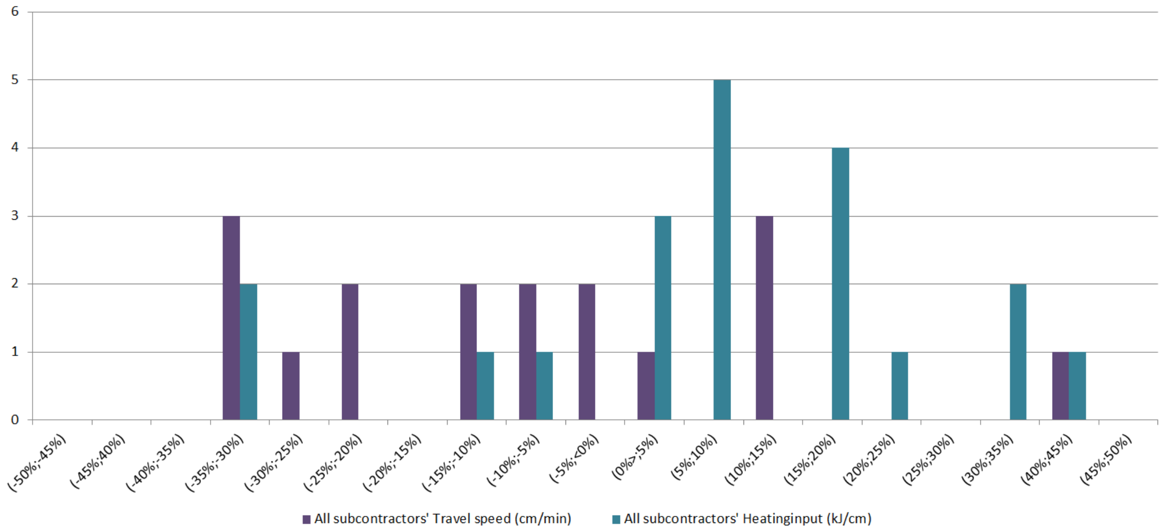

Figure 33. The histogram of the percent exceedances of travel speed and arc energy.

4.3 Delays and problems in receiving the qualifications of subcontractors

The results of qualification process problems are presented in this chapter divided into interviews, frequencies, statistical key figures and box plots. Problems in the qualification process are considered by quantity and delays. Internal subcontractors, Meyer Werft as well as the different departments of the shipyard are interviewed for revealing the procurement process and improvement ideas. Quantities of qualification problems and their delay times are presented by frequencies and statistical key figures. The main qualification problems are analyzed by box plots.

4.3.1 Interviews

Following chapters presents the results of interviews. The current process is presented in the first paragraph. The second paragraph introduces welding quality managing for a new welder of the parent company of Meyer Turku. The results of the interviewed subcontractors, which are Subcontractor F, D and J, are presented in last paragraphs.

The functional diagram of a qualification checking process was not defined before this thesis. In appendix VI the functional diagram is based on the interviews which were made in different departments of Meyer Turku. The procurement department of Meyer Turku demands documents from the organization of subcontractors to fulfill laws. The documents should be sent to Meyer Turku one week before a welder arrives. At the gate of Meyer Turku identity, occupational safety card and hot work license of the welder is checked. If the documents are approved, the welder will be sent to a HSE-exam (Health Safety Environment) before the welder is allowed to work for the shipyard. If production departments are not checked the welding qualifications of the welder, it is possible the welder will weld at least one week before QC and welding department will check the qualifications of the welder.

The parent company of Meyer Turku has a preproduction test for every new welder. Their process for a new welder is as follows. A welding supervisor should receive information and qualifications of a new welder one week before arriving. The new welder does a preproduction welding test and the qualifications are usually given one to two days before start of a welding work. The preproduction test simulates production circumstances which are presented in Appendix VII. It presents a manhole and proportions as well as a room where test pieces are welded. If the new welder does not pass the test in two attempts, he will not weld in the yard. The test is passed by 70 % of welders. (Grobenstieg, 2016.)

Subcontractor F has certified ISO 9001 and 14001 as well as OHSAS 18001 standards. They do not have access to the web based information management program of Meyer Turku but the paper documents have been available by a request. Welding quality requirements are delivered with an inquiry. Laminated A6 paper size WPSs have been seen as a good developing idea because the location of WPSs is not always clear. The welders are qualified at Inspecta of Ukraine and Lithuania and prolongations are updated in Finland. Subcontractor F has only a normal folder for the qualifications of the welders. It has been seen as good idea to get the information of update needs from Meyer Turku before the deadlines of prolongation and expires. Prolongations have been seen easier to update directly to a qualification register.

Subcontractor D has certified ISO 9001. The quality requirements of Meyer Turku have seen to be difficult and complex. The locations of WPSs are not clear for welders and they are not interested in using WPSs because productivity would decrease. Also connections between WPSs and quality have not been understood. All welders of Subcontractor D are qualified in the shipyard of Meyer Turku. A change for updating prolongations and expired qualifications are not needed. If Subcontractor D can get the information of expiring qualifications through the email, they can send the information of welders who are not working in the shipyard anymore. Impurities are the major problems of welding quality problems instead of welding as WPS according to the management of Subcontractor D. They cannot meet the quality requirements because the quality of previous phases is not sufficient enough.

The web based information management program of Meyer Turku is not available for Subcontractor J. The welding quality requirements are gotten with an inquiry and a few times welders are advised by QC department of Meyer Turku. The WPSs are used and their locations are well-known. The laminated A6 size WPSs have been seen to be a good improvement idea by Subcontractor J. Their welders are qualified in their own shipyard and Finland. The welding qualifications, which are tested in the shipyard of Meyer Turku, are not approved in their own shipyard. A current email system for updating prolongation and expired qualifications is suitable for Subcontractor J. They check all qualifications monthly in Armenia. The qualifications of new welders are sent before they arrive at Meyer Turku. According to Subcontractor J they send only the best welders to Finland because traveling and other costs are notable.

4.3.2 Frequency

Average weekly qualification shortcomings were divided into different types which are shown in Figure 34. Colors show the weekly quantities of different problems. For example, orange mistakes have been one week and greens have been three weeks on the list. Six months prolongations and receiving the qualifications of new welders can be seen as main problems.

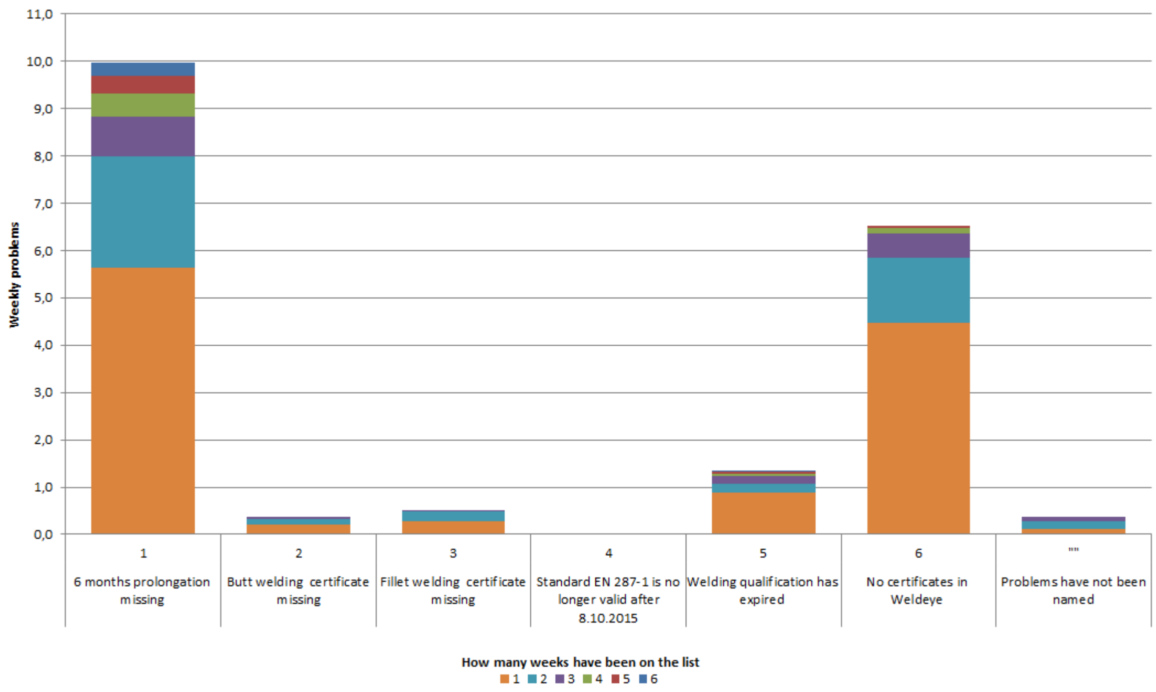

Figure 34. Weekly average qualification shortcomings.

Moreover the average weekly qualification shortcomings were divided by weekly quantities of welders in Figure 35. In addition the inverse of weekly quantities of welders was calculated. Connection between the quantity of welders and qualification shortcomings can be detected. If subcontractor has more welders, the shortcomings of each welder decrease generally. The fewer shortcomings per welder, the more welders the company has generally. Subcontractor A can be detected to be an exception.

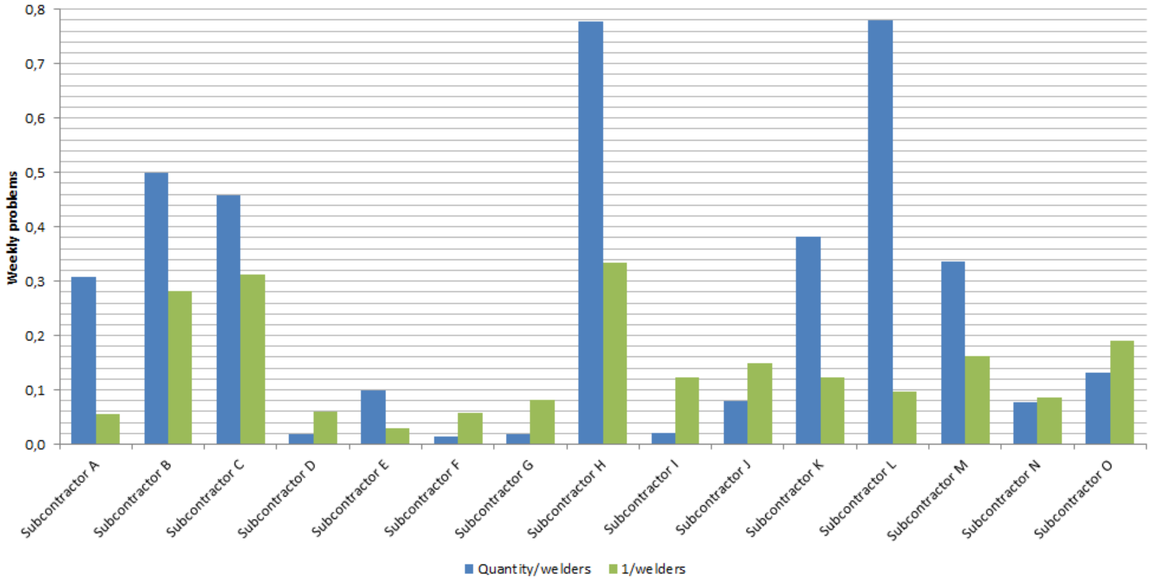

Figure 35. Weekly average qualification shortcomings divided by the weekly quantities of welders and the inverse of weekly quantities of welders.

4.3.3 The statistical key figures of shortcomings

The statistical key figures of average weekly qualification shortcomings are presented in table 8 using equations 4, 5, 6 and 7. The shortcomings of six months prolongations and no certificate in web based qualification register are the most common qualification mistake types. The highest extreme values are for the shortcomings of 6 months prolongations and expired welding qualifications. The higher mean indicates longer update time for outdated or missing qualifications. Missing qualifications are dispersed less than outdated qualifications. The standard error of sample is lower for qualification shortcomings and 6 month prolongations because the quantity of missings is higher.

Table 8. Statistical key figures of how many week problems have been on the list.

	6 months prolongation missing	Butt welding certificate missing	Fillet welding certificate missing	Welding qualification has expired	No certificates in a web based qualification register
Percent of population	53 %	2 %	3 %	7 %	34 %
Min	1.0	1.0	1.0	1.0	1.0
Max	7.0	3.0	3.0	6.0	5.0
Mean	1.9	1.6	1.5	1.7	1.4
Variance	2.0	0.5	0.4	1.5	0.6
Standard deviation	1.4	0.7	0.6	1.2	0.8
SE of sample mean	0.1	0.2	0.2	0.2	0.1

4.3.4 The box plots of shortcomings

In Figure 36 the box plots of the deviation of 6 months prolongations shortcomings are presented. After two weeks any observation cannot be detected. Deviation narrows and median drops which indicate that subcontractors start to correct mistakes after they receive the information of 6 month prolongation mistakes.

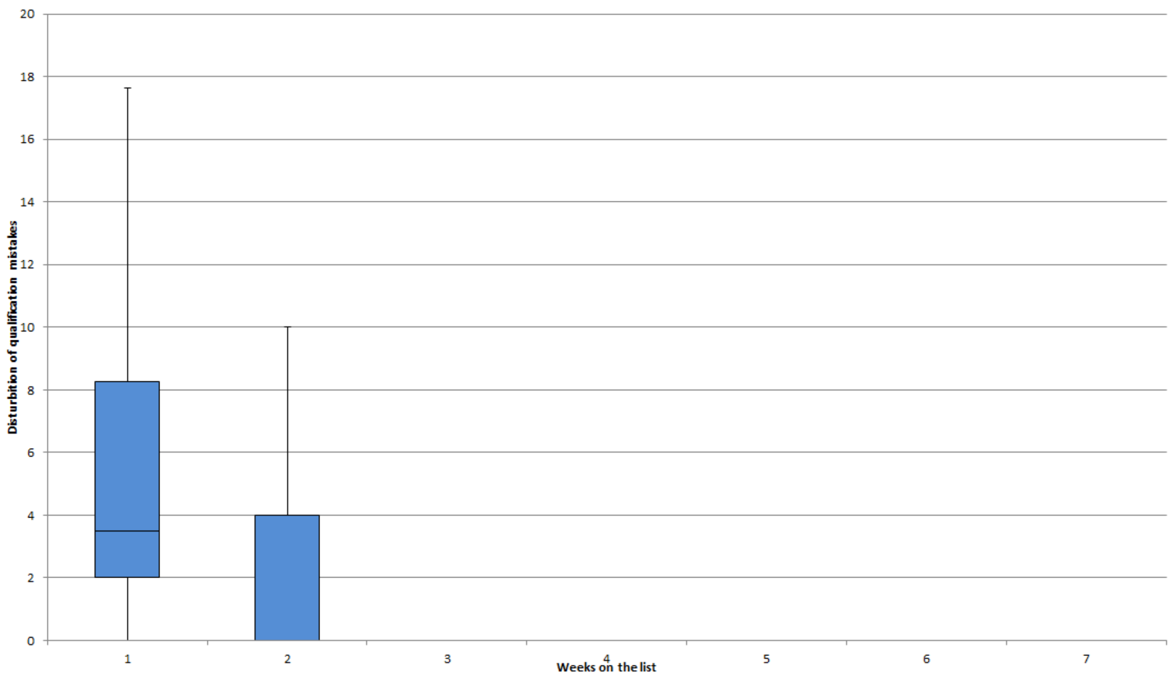

Figure 36. The box plot of the deviation of 6 months prolongations mistakes.

The box plots of the distributions of the shortcomings of new welders are presented in Figure 37. Any observation cannot be detected after third week and distribution is downward. Median drops and distribution narrows which indicate that subcontractors start to correct mistakes after they receive the information of qualification problems. Diversity of the both 6 months prolongation and the missing qualifications are different.

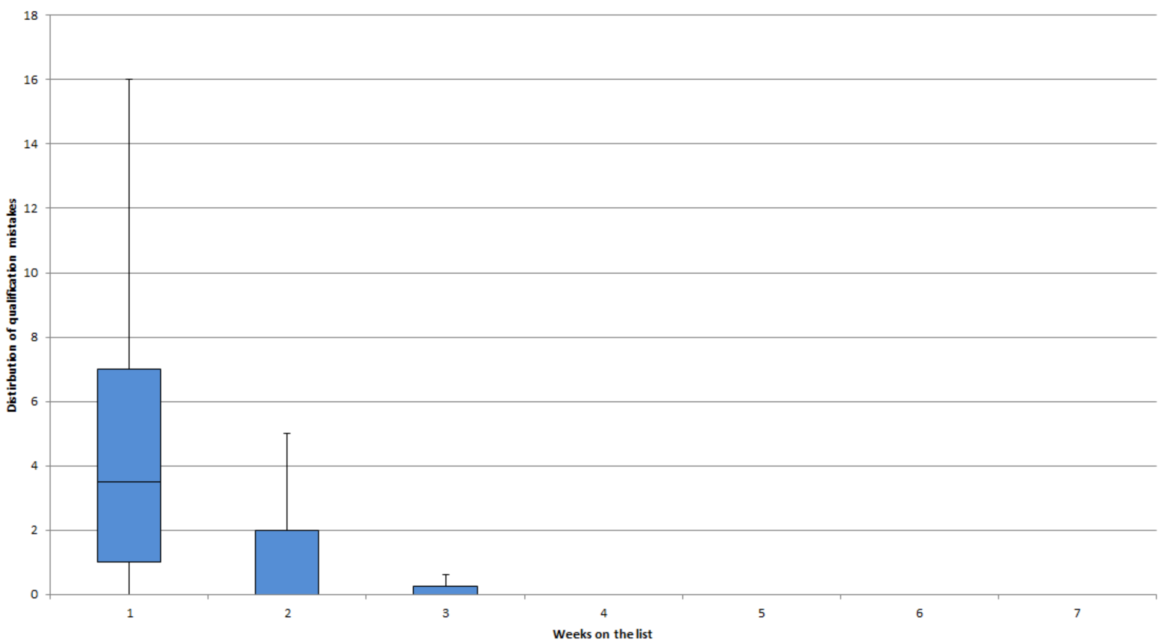

Figure 37. The box plot of the deviation of missing certificates.

5 DISCUSSION

In this chapter the analyzed results were used for answering the research questions. The chapter is divided into eliminating wasted hours from managing the qualifications of the subcontracted welders, usability of IoT welding applications, implementing tools and philosophies as well as quality standard in the area of this thesis. Also the created tool is suggested to be used in the future for managing the welding quality of subcontractors.

5.1 Managing the qualifications of subcontracted welders

As the results and analysis reveal more than half of qualification problems are corrected in one week and in some cases corrective actions take four weeks. Main problems are the prolongation expires and the shortcomings of qualifications, which are not sent to the qualification register on time. Meyer Turku has not implemented a detailed quality procedure for managing the welder qualifications. The suitability of welders must be checked before they have access to the shipyard. In cases when the welds of an unqualified welder are not removed, the hull is not welded according to ISO 3834-2 standard whose a purpose is to fulfill ISO 9001 standard. Welders can cause unnecessary quality costs without the welder qualifications. An alternative functional diagram for managing qualifications is presented in appendix VIII.

If production departments do not check the qualifications of new welders, they have an opportunity to weld one week before QC department has possibility to request qualifications. The QC department receives the weekly list of the new welders in the beginning of the next week. The production departments have information about new welders immediately but they do not have the time or the knowledge of inspecting qualifications. The procurement department is aware of new workers but they do not have the identified information of welders and fitters or the knowledge of inspecting qualifications. The QC department has the necessary knowledge but the information of welders does not arrive early enough. The qualifications of welders could be demanded at the same time as A1-forms and then sent them to the QC department for checking. The checking must be done before welders arrive at the gate of Meyer Turku. The list of qualified welders and welders with a scheduled qualification test times could be sent to the gate every Friday afternoon by QC department. When the gate has information of qualified welders they will not pass unqualified welders inside the shipyard. Subcontractors can be informed that if the qualifications of welders have not sent with A1-forms or qualification test time has not reserved, welders will be identified as fitters. They are not allowed to weld. A fine will be used for punishing unqualified welding works.

Subcontractors do not have a welding qualification management system for managing the expiry dates of qualifications. They have updated prolongations in two weeks after the information of expires is sent to them by the QC department of the shipyard. So the expire warnings of expiring prolongations should be sent to subcontractors two week before expiry dates so that they have enough time to update the certificates. This kind of an automatic expiring system, which sends emails two weeks before expiry dates, is built in a web based qualification register but automatic emails do not work anymore. The suspected reason is the lack of information in data. In addition, large amount of inactive welders cause problems for the data management. When welder leaves the shipyard his status should be inactivated. Repairing these problems, qualification expiry warnings can be sent up front to subcontractors automatically. In plans, Meyer Turku will change to a new web based qualification register what is actually based on an old system. Data must be added to meet the requirements of the new system. The inactive welders should be removed and emails, where the notifications will be sent, must be corrected.

5.2 Problems in the records of NDT inspections

Without reliable tracking the success of developments are difficult to verify. The reporting of NDT-results sustains a sampling bias which is caused by issues in the sample selection. Inspection targets are based on the random choices of inspectors according to NDT-plans. In reality the human mind causes a sampling bias. For example the other inspection targets are harder to reach and then probability for choosing easier targets are higher. Also probability to achieving the comparable NDT-plans between ships must be noticed because the quantity of variables is notable.

The sampling bias of RT-inspection is problematic in three ways. They can be separated into the bias of the random choices of inspectors, already repaired defects as well as defects which are too long for one film. The already repaired and too long defects can be separate from the data. Then only the sampling bias is problematic. The sampling bias can be avoided by separating the length of all welds of the hull into sections. The workload of raffling sections requires analyzing. If the types of the welding defects are wanted to be separated from relative defect lengths, the major causes of the welding defects must be separated. Now the several types of the welding imperfections are reported but the major defect, that caused repairs, is not separated. The separating is important that the sampling bias is not caused by welding imperfections.

UT-inspection is even more problematic than RT-inspection. The results of this thesis show that UT-inspection is used only for seeking welding defects. Basically the searching of welding defect is sensible but it cause illogical relative welding defect length. It can be deduced because the inspection range covers usually the length of the defects. Also the sample standard deviation signals the width of the inspection range changes less than the length of the defects. The problem of the sampling bias is the same with RT-inspection but additional inspection cannot be separated from the data. The inspection lengths must be defined.

NDT-plan concentrates on areas which are important for durability. The inspection areas are selected by experience. The experience is changing and the most important areas by durability are not comparable between different hulls. This causes that the inspection areas of NDT-plans are not comparable. The random sample must be taken from the area where external actions are the same. Then the hulls will be comparable. These areas are difficult to define because the durability depends on many variables. If the welds of hulls can be separated into sections, then double amount of weld sections will be inspected in critical areas by durability and separate other half from the statistics.

5.3 Preventing welding defects by IoT and cloud based systems

The IoT welding systems, which are presented in this thesis, do not solve the welding quality issues by themselves. The measuring range is limited by current and voltage exceedances. Some of the IoT welding systems enable travel speed and arc energy measurements if the lengths of welding runs are entered into a program. For example the WPS inspection, which were used for getting the results of this thesis, measures current, voltage, gas flow, travel speed and arc input. Other variables in welding can only be controlled by the know-how of welder and additional controlling.

IoT welding systems are difficult to manage because of large amount of data. For example the quantity of WPS exceedances can be so high that the welding engineer misses the most critical issues in the data. The most critical errors must be separated by adjusting the limitations of WPS or allowing small exceedances in the program. Other problem is the sampling bias. Numerous IoT units must be used to getting reliable data for comparing subcontractors. Another option is to use IoT units in the most critical joints without comparing subcontractors. In the next paragraphs the usability of IoT welding systems is considered for preventing the most common welding defects.

If the theoretical reasons of welding defects are compared to the results of WPS inspections, the current exceedances and impurities are the most possible reasons of the welding defects in the shipyard. The current exceedances can be detected by all introduced IoT welding systems. The IoT systems do not measure the flow of gas so elongated cavities and gas pores can be noticed only by manual WPS inspections. Longitudinal cracks can be prevented partly by IoT systems because insufficient voltage can be measured. Low travel speed and arc energy over the WPS limit are possible reasons but these are not measurable by IoT without the data of the lengths of welding runs. Lack of fusion can be caused by voltage, current, travel speed or arc energy exceedances.

Also insufficient knowledge, like welding over convex beads or wrong torch positioning, can cause lack of fusion. From RT-inspections impurities are suspected to be remarkable reasons for the welding defects which can only be avoided by increasing awareness also in previous work phases. It is also a method to avoid the too wide grooves, convex beads, wrong torch positioning, wrong ending technique of a weld run and insufficient preheating as well as moisture which are connected to lack of fusion, slag inclusion, crater pipes, porosities and elongated cavities.

IoT welding systems do not guide the welders to increase awareness of impurities, moisture, insufficient preheating, welding over convex beads and wrong geometries of grooves as well as crater pipes. Subcontractors having a low level of awareness can be instructed to ask from VT-inspectors if the prefabrications are acceptable. If the level of additional inspection is wanted to increase, the inspection process needs to be flowing. The cloud based system would help to remove middlemen from the process and ensure every inspection targets are reported and repaired. The inspecting will be continued until the level of awareness will reach the acceptable level by welders themselves. If the knowledge of the subcontracted welders was questionable, a pre-production test could be adopted. The pre-production test can be planned according to the most common reasons of welding defects in the shipyard.

5.4 Implementing welding quality standards and management philosophies

The responsibilities must be defined into the qualification checking process of welders complying with ISO 9001 standard. Also a procurement process of subcontracting must be defined. The potential subcontractors should also be reviewed by the QC department. The welding engineer or a person with similar expertise should have the applied technical review of ISO 3834 standard. The subcontractors should be compared according to chosen indicators which measure their corresponding to ISO 3834 standard.

Lean philosophy is implemented for improving quality processes. The process, what is presented in appendix VIII, is implemented without bureaucracy what is not required. The improved qualification checking process ensures that unqualified welders do not have accesses and cause quality costs to the shipyard of Meyer Turku.

For subcontractors TWM is considered on its guidelines. All of the welders of subcontractors have not internalized that welding is science. Some of subcontractors have seen that welding quality cannot be improved if productivity is not decreased. Some of welders do not see a reason to weld as specified in the WPS. In implementing TWM subcontractors must know how they meet the quality requirements. If measurable goals are presented in a time-frame, a shared road-map can be defined for reducing quality problems If hands-on leadership was wanted in the shipyard, it would be defined in technical review. Defining the weaknesses and strengths of the subcontractors, the subcontractors can be selected. They can be used for the production processes which have the highest quality costs. The strong foundation can be achieved when subcontractors are well-instructed and they have applied the processes of the shipyard. For example IoT offers benefits for both sides. Meyer Turku achieves better quality and subcontractors can complete weld works at once and save money. Being partners in cooperation, the training of subcontractors can be tutored better if turnover of welders can be decreased.

5.5 Managing the welding quality of subcontractors

Subcontractors need to be informed of their progress in development which is based on measured data. The data can be collected and analyzed by the methods what are introduced in this thesis. If subcontractors can compare them to others, they will see their position in quality ranking. It can increase competition between the subcontractors. Anonymity of subcontractors can be kept by describing them as A, B, C for example. Target levels must be defined. If a subcontractor does not reach the target level, the new contract cannot be made. This can be checked during the technical review before a new contract is signed. Influence of quality ranking is not easy to prove because quality costs are often hidden or not measured. Another way is to give fines to underperformed subcontractors according to the quality ranking. All next actions must be written down separately in the contracts and discussed with subcontractors monthly.

In addition work delays and the marking identifiers of welders are also important measuring units. The quality costs of work delays can increase high. The production department should define the harm of work delays because they have the best knowledge for its effectiveness. All information of the work delays should be collected into one database thus all departments can use it for comparing subcontractors. Welders must mark welds with their identifier. The companies are responsible for that their welders follow rules. The subcontractors can be fined if their welders do not mark the identifiers. For example the marking a starting point before welding and ending point after welding, subcontractors can be checked during WPS inspection. Then the sampling bias is the same for both of them. The WPS inspection can be performed and analyzed as introduced in this thesis.

5.6 Significance of the topic

The topic of this thesis proved to be wide and challenging. Because the size of the organization, reasonable argues is needed before changes can be implemented. This thesis concentrates on giving the justified information of problems and creating tools for improving and monitoring quality. Time period is long for noticing changes. Still it has been suggested that research questions are answered and subcontractors can already be managed by the WPS inspections and qualification shortcomings.

The weaknesses of the old qualification checking process were found. The analyzed results are reliable. It is expected the new process needs fewer resources and works better. The changes, what is needed, can be made easily and they do not add bureaucracy. The resistance of change and surprises are threats.

Theoretical reasons for welding defects are referred because the root causes of the welding defects are not possible to define afterwards. It skews results. In addition the sampling bias is problematic in WPS inspection. The welders cannot be chosen by raffling because the location information of welders is not available without informing upcoming inspection. The results favor the welders which are coming along the general route of the inspector.

The qualification assurance tools can be utilized. The IoT welding systems can be used preventing defects but its overall results are hard to estimate. In measuring subcontractors full sample can be implemented by the IoT welding systems and then there is not the bias of the random sample anymore.

5.7 Future work

All introduced methods lean on NDT-records. The results must be comparable that the influences of changes can be noticed for continual improvement. The already repaired and long defects should be separate from the data used for comparing the subcontractors.

Improvements will be implemented in practice. Then they can be exploited in the process of purchasing subcontractors. Specific needs and requirements for subcontractors are needed to define.

The sampling bias of WPS inspection could be decreased to get more exact data. However the results are now suitable for noticing remarkable progress in development. Also the shortcomings of the qualifications of welders should be measured. If a preproduction test or theory exam will be applied by the result of this thesis, the test or exam must be defined.

6 SUMMARY

Meyer Turku is a family-owned shipbuilding company specialized in cruise ships, car-passenger ferries and special vessels. Production capacity has been started to increase after receiving a record-breaking number of orders which will be delivered in the following years. Development and clarification of the welding quality procedures have been started. The research in this thesis has been started as a part of these improvements. In some cases subcontracted welders have started welding work before their qualifications and competence are checked by Meyer Turku. This research was aimed to introduce a proactive control method for improving welding quality of internal subcontractors who weld under the quality system of Meyer Turku in the area of the shipyard. The method must be easy to use and scalable for a larger number of subcontractors in the future.

Quality is subjective. Normally quality is connected to an excellent product or service which fulfills or exceeds our expectations. Quality costs can be separated in the costs of good and poor quality. The later the poor quality is detected, the more expensive it becomes. Quality can be managed by different standards, tools and philosophies.

The quality system of the shipyard is certified according to SFS-EN ISO 9001:2008, SFS-EN 3834:2005, SFS-EN ISO 14001:2004 and OHSAS 18001:2007. Quality philosophies as lean, TQM and TWM are suitable tools in the shipyard for improving hands-on quality management. The process of welding qualification management is improved using lean philosophies. Hierarchy is reduced and quality deviations should not get through the process anymore. This can be implemented with the existing web based qualification register and Excel as well as disciplining welder qualification management. SFS-EN ISO 9001:2015 is based on TQM and its continuous improvement. The central points of TWM should be kept in mind for managing internal subcontractors.

Welding in accordance with WPS can be measured and analyzed by voltage, current, gas flow, travel speed and arc energy. Frequencies, statistical key figures and graphics can be used for representing the numerical and categorical variables of the WPS inspections. A full random sample cannot be applied to the WPS inspections.

The most common welding defects are lack of fusion, slag inclusions, crater pipe and porosity according to UT and RT -records. It seems that the frequencies of slag inclusion and porosity correlate to welding parameter inspections. Correlation between the welding defects and parameter inspections may not be argued because impurities can also cause these welding defects.

Nowadays welding machine manufactures provide their IoT solutions which measure current and voltage. In addition welder qualifications can be checked by some welding machines of Kemppi and Esab. The current exceedances, which can be reasons for some of the most common welding defects, can be detected by IoT welding systems.

If the prefabrications of welds are wanted to inspect by Meyer Turku, an inspection process needs to be flowing. A cloud based documenting would help to remove middlemen from the process and ensures that every inspection targets are reported and repaired. The inspections will be continued until the level of awareness will reach the acceptable level by welders themselves. If the knowledge of subcontracted welders is questionable, a pre-production test can be adopted which simulate field conditions. The test can be planned according to the most common causes of welding defects in the shipyard.

The welding defects, the shortcomings of welder’s qualifications and the welding in accordance with welding procedure specifications can be measured continuously by the introduced methods. Next these will be implemented in practice.

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APPENDIX I

Contents of SFS-EN ISO 9001:2015.

Contents

APPENDIX II

The levels of SFS-EN ISO 3834:2005.

No.	Element	ISO 3834-2	ISO 3834-3	ISO 3834-4
1	Review of requirements	review required		
		record is required	record may be required	record is not required
2	Technical review	review required		
		record is required	record may be required	record is not required
3	Sub-contracting	treat like a manufacturer for the specific subcontracted product, services and/or activities, however final responsibility for quality remains with the manufacturer		
4	Welders and welding operators	qualification is required		
5	Welding co-ordination personnel	required		no specific requirement
6	Inspection and testing personnel	qualification is required		
7	Production and testing equipment	suitable and available as required for preparation, process execution, testing, transport, lifting in combination with safety equipment and protective clothes		
8	Equipment maintenance	required to provide, maintain and achieve product conformity		no specific requirement
		documented plans and records are required	records are recommended	
9	Description of equipment	list is required		no specific requirement
10	Production planning	required		no specific requirement
		documented plans and records are required	documented plans and re-cords are recommended	
11	Welding procedure specifications	required		no specific requirement
12	Qualification of the welding procedures	required		no specific requirement
13	Batch testing of consumables	if required	no specific requirement	
14	Storage and handling of welding consumables	a procedure is required in accordance with supplier recommendations		in accordance with supplier recommendations
15	Storage of parent material	protection required from influence by environment; identification shall be maintained through storage		no specific requirement
16	Post-weld heat treatment	confirmation that the requirements according to product standard or specifications are fulfilled		no specific requirement
		procedure, record and traceability of the record to the product are required	procedure and record are required	
17	Inspection and testing before, during and after welding	required		if required
18	Non-conformance and corrective actions	measures of control are implemented		measures of control are implemented
		procedures for repair and/or rectification are required		
19	Calibration or validation of measuring, inspection and testing equipment	required	if required	no specific requirement
20	Identification during process	if required		no specific requirement
21	Traceability	if required		no specific requirement
22	Quality records	if required		

APPENDIX III

Example of the RT-records.

Date	Week	Bldg	Block	Weld. proc.	Insp. length	Rep. length	Def. type	Welder A	Welder B	Foreman	Company	Object	Notes	Report
ke 20.05.2015	15/21-22	175D	384		6 000	6 000	4011					Deck 3 P fr. 205-239		COY88
ke 20.05.2015	15/21-22	175D	385		12 000	12 000	4011					Deck 4 S fr. 205-239		COY90
ke 20.05.2015	15/21-22	175F	3233		1 500	760	4011					Deck 3 S fr. 60-85		COY86
ke 20.05.2015	15/21-22	175D	384		10 000	10 000	4011					Deck 3 S fr. 205-239		COY89
ke 20.05.2015	15/21-22	175F	3243		20 000	20 000	4011					Deck 4 P fr. 60-85		COY84
ke 20.05.2015	15/21-22	175D	384		6 000	6 000	4011					Deck 3 P fr. 205-239		COY88
ke 20.05.2015	15/21-22	175F	3243		20 000	20 000	4011					Deck 4 P fr. 60-85		COY84
ke 20.05.2015	15/21-22	175F	3233		1 500	760	4011					Deck 3 S fr. 60-85		COY86
ke 20.05.2015	15/21-22	175F	3243		20 000	20 000	4011					Deck 4 P fr. 60-85		COY84
ke 20.05.2015	15/21-22	175F	3233		1 500	760	4011					Deck 3 S fr. 60-85		COY86
ke 20.05.2015	15/21-22	175D	384		6 000	6 000	4011					Deck 3 P fr. 205-239		COY88
ke 20.05.2015	15/21-22	175D	384		10 000	10 000	4011					Deck 3 S fr. 205-239		COY89
ke 20.05.2015	15/21-22	175D	385		12 000	12 000	4011					Deck 4 S fr. 205-239		COY90
ke 20.05.2015	15/21-22	175D	385		20 000	20 000	4011					Deck 4 P fr. 205-239		COY91
ke 20.05.2015	15/21-22	175D	384		6 000	6 000	4011					Deck 3 P fr. 205-239		COY88
ke 20.05.2015	15/21-22	175D	385		12 000	12 000	4011					Deck 4 S fr. 205-239		COY90
ke 20.05.2015	15/21-22	175F	3233		1 500	760	4011					Deck 3 S fr. 60-85		COY86
ke 20.05.2015	15/21-22	175D	384		10 000	10 000	4011					Deck 3 S fr. 205-239		COY89

APPENDIX IV

Example of the UT-records.

Date	Week	Bldg	Block	Weld. proc.	Insp. length	Rep. length	Def. type	Welder A	Welder B	Foreman	Company	Object	Notes	Report
ma 08.06.2015	15/23-24		290		480	15	2024					Block 290 bottom shell fr. 3 P	99	46
ma 08.06.2015	15/23-24		290		480	15	2024					Block 290 bottom shell fr. 3 P	99	46
ke 01.07.2015	15/27-28		510		350	350	202					GB 510, fr. 67-71, P-side	DNV4	DNV4
ke 01.07.2015	15/27-28		43X		330	20	202					Block 43X fr. 85-111 deck 10 NB1389PM-2484	DNV5	DNV5
ke 01.07.2015	15/27-28		510		350	350	202					GB 510, fr. 67-71, P-side	DNV4	DNV4
ke 01.07.2015	15/27-28		43X		330	20	202					Block 43X fr. 85-111 deck 10 NB1389PM-2484	DNV5	DNV5
pe 24.07.2015	15/29-30		590-620L		480	70	2011					Block 590-620L BS+Deck 0 fr. 150 S+P	BS 147	60
pe 24.07.2015	15/29-30		590-620L		480	30	2011					Block 590-620L BS+Deck 0 fr. 150 S+P	BS 148	60
pe 24.07.2015	15/29-30		590-620L		480	400	2011					Block 590-620L BS+Deck 0 fr. 150 S+P	BS 149	60
pe 24.07.2015	15/29-30		590-620L		480	70	2011					Block 590-620L BS+Deck 0 fr. 150 S+P	BS 147	60
pe 24.07.2015	15/29-30		590-620L		480	30	2011					Block 590-620L BS+Deck 0 fr. 150 S+P	BS 148	60
pe 24.07.2015	15/29-30		590-620L		480	400	2011					Block 590-620L BS+Deck 0 fr. 150 S+P	BS 149	60
la 01.08.2015	15/31-32		740A-F		480	40	2013,2024,5012					Block 740 A-F deck 14-12 fr. 189 S+P	Deck 12 163	63
la 01.08.2015	15/31-32		740A-F		480	30	2024					Block 740 A-F MAXI deck 14-12 fr. 189 S+P	Deck 14 152	62
la 01.08.2015	15/31-32		740A-F		560	90	2024					Block 740 A-F MAXI deck 14-12 fr. 189 S+P	Deck 12 159	62
la 01.08.2015	15/31-32		740A-F		560	60	2024					Block 740 A-F MAXI deck 14-12 fr. 189 S+P	Deck 12 162	62
la 01.08.2015	15/31-32		740A-F		520	480	402					Block 740 A-F MAXI deck 14-12 fr. 189 S+P	Deck 14 156	62
la 01.08.2015	15/31-32		740A-F		560	90	2024					Block 740 A-F MAXI deck 14-12 fr. 189 S+P	Deck 12 159	62
la 01.08.2015	15/31-32		740A-F		560	60	2024					Block 740 A-F MAXI deck 14-12 fr. 189 S+P	Deck 12 162	62

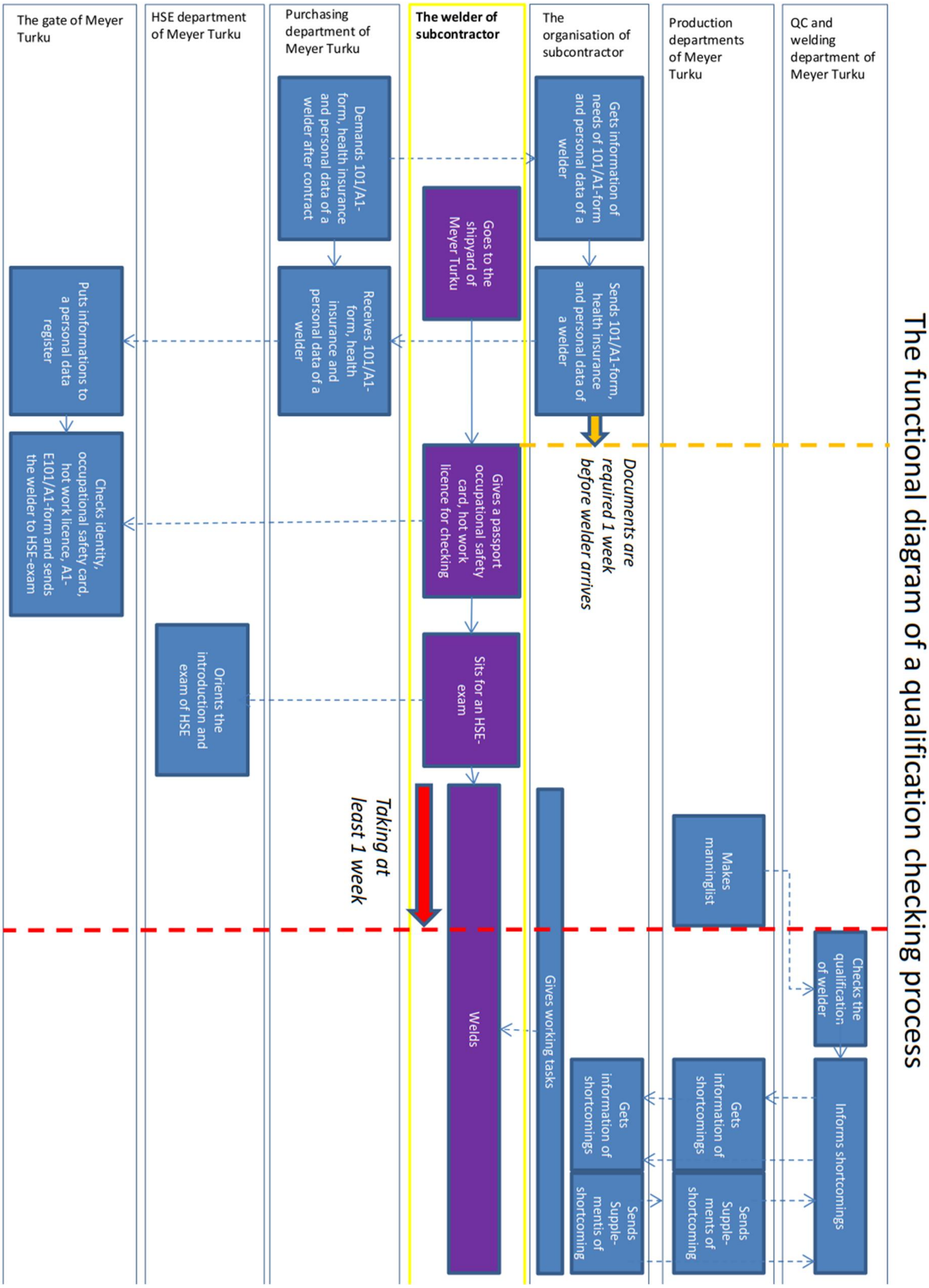
APPENDIX V

Example of qualification shortcomings list.

			1	*6 months prolongation missing*	
Week	20		***2***	*Butt welding certificate missing*	
Company			***3***	*Fillet welding certificate missing*	
			4	*Standard EN 287-1 is no longer valid after 8.10.2015*	
			5	*Welding qualification has expired*	
			6	*No certificates in Weldeye*	

ID	Name		**Problem**	**Information**	**Weeks in list**
			1	NF-EN 287-1:2011 136 P BW 1.1 P t14.0 PF ss mb	2
			1	NF-EN 287-1:2011 136 P FW 1.1 P t10.0 PD ml	2
			1	NF-EN 287-1:2011 136 P FW 1.1 P t10.0 PD ml	2
			1	NF-EN 287-1:2011 136 P BW 1.1 P t14.0 PF ss mb	2
			6		5
			1	NF-EN 287-1:2011 136 P FW 1.1 P t10.0 PD ml	3
			1	NF-EN 287-1:2011 136 P BW 1.1 P t12.0 PF ss mb	3
			1	NF-EN 287-1:2011 135 P BW 1.1 S t12.0 PF ss mb	3
			1	NF-EN 287-1:2011 135 P FW 1.1 S t10.0 PD ml	3

An old qualification checking process.



APPENDIX VII

A preproduction test at the parental company

A new qualification checking process.