University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/Specialization: Industrial Economics Project Management	Spring semester, 2016 Open access
Writer: Håkon Kjerkreit	…………………………………………………………… (Writer's signature)
Faculty supervisor: Petter Osmundsen	
Thesis title: Costs of not Following Common Standards; A Case Study of Cost Implications of Using Customer Specific Requirements Instead of Industry Standards	
Credits (ECTS): 30	
Key words: Subsea Production systems Petroleum Technology Standardization Oil & gas Fasteners Bolted Joints Specifications	**Pages:** 48 + enclosure: 2 pages Stavanger, 15th of June, 2016

Abstract

In recent years, costs of subsea production systems on the Norwegian Continental Shelf has escalated. In combination with a plunging oil price, this has led to reduced margins for the companies. In order to survive the Norwegian subsea industry need to change from being technology driven, to being cost efficient through the use of standardization, simplification and smarter ways of working.

With the cyclic nature of the Oil & Gas industry, cost escalations after periods of high oil price has been a returning problem. Several initiatives has been raised to facilitate standardization of materials and testing, which has led to the development of the NORSOK standards, and later the ISO 13628 standard for subsea production systems. Even if most of the major upstream companies operating on the Norwegian Continental shelf have contributed to the development of the NORSOK standards, they still apply their own set of technical requirements and test requirements for their equipment.

This thesis investigates cost implications that arise from use of customer specific requirements, and barriers preventing use of common standards through use of methods from exploratory case studies. The study focuses on fasteners, one of the most basic components of any system, in order to give an understanding of the challenges that exists for standardization. The findings are discussed for how they can be relevant for other types of equipment used in the subsea industry.

Fasteners are by their nature ideal for mass production. However, the market for fasteners in subsea use is rather small on a global scale. This makes standardization and well-considered fastener selection critical in order to achieve benefits of scale.

The findings indicate that the requirements imposed by the oil companies are not the most decisive cost drivers. Rather it is the lack of coordinating of requirements between companies and standards, and the large number of different fasteners in use that are found to be the main cost drivers. In addition, the procurement strategy applied by most companies promotes low volume orders, and thus does not give room for production to achieve production optimum quantities.

In the period 2010-2011 the price of one of the analyzed fasteners increased 60 times. This coincides with the launch of revision 2 of Statoil TR3101. Parts of these costs were related to the introduction of fastener traceability, which had not been sufficient before the release of the TR. The price has declined as fastener manufacturers has become familiar with the new requirements. However, the average price is still over ten times the original for the part numbers analyzed.

Contents

ABSTRACT I

CONTENTS II

ACKNOWLEDGEMENTS V

1. INTRODUCTION 1

1.1 LIMITATIONS 3

2. REVIEW OF LITERATURE 5

2.1 AN INTRODUCTION TO STANDARDS FOR SUBSEA FASTENERS 5
2.1.1 THE NORSOK STANDARDS 6
2.2 STANDARDIZATION 8
2.2.1 THE VALUE OF STANDARDIZATION 9
2.2.2 STANDARDIZATION CHALLENGES 9
2.2.3 PREVIOUS STANDARDIZATION INITIATIVES IN THE SUBSEA INDUSTRY 9
2.3 BOLTING TECHNOLOGY – AN INTERDISCIPLINARY SUBJECT 10
2.3.1 FAILURE MECHANISMS FOR BOLTS 11
2.4 PREVIOUS RESEARCH ON EFFECTS OF STANDARDIZATION IN O&G 14

3. METHODOLOGY 17

3.1 THE CASE STUDY METHOD 17
3.2 RESEARCH METHOD 17
3.2.1 INTERVIEW STRUCTURE 19
3.3 DATA ANALYSIS 19
3.4 BIASES OF THE PARTICIPANTS 20
3.5 THE GOAL OF THE RESEARCH 20

4. RESULTS AND DISCUSSION 21

4.1 COST DRIVING FACTORS 21
4.1.1 LOW VOLUME PROCUREMENT 22
4.1.2 TOO MANY DIFFERENT PARTS IN USE 23
4.1.3 COST OF AUDITS 25
4.1.4 SYSTEMS SUPPLIER PROVIDING ADDITIONAL REQUIREMENTS 25
4.1.5 COST DEVELOPMENT FOR A SELECTION OF FASTENERS 26
4.1.6 COST OF MAINTAINING THE STANDARDS 29
4.1.7 EFFECTS OF THE REQUIREMENTS IN USE 29

4.2 BARRIERS FOR USING COMMON STANDARDS 31
4.2.1 LACK OF AN AGREED UPON COMMON STANDARD 31
4.2.2 WHY NOT NORSOK STANDARDS FOR FASTENERS 31
4.2.3 GAPS BETWEEN COMMON STANDARDS IN USE 32
4.2.4 INCONSISTENCY BETWEEN STANDARDS AND VAGUE SPECIFICATIONS 32
4.2.5 LACK OF TRUST 34
4.2.6 CONFLICTING ISO STANDARDS 35
4.3 POSSIBLE LEARNINGS FROM OTHER INDUSTRIES 35
4.3.1 DOCUMENTATION REQUIREMENTS 36
4.3.2 DESIGN PHILOSOPHY 37

5. RECOMMENDATIONS 39

5.1 COMMON AGREEMENT ON WHICH STANDARD SHOULD BE USED 39
5.2 STANDARDIZATION IN PRODUCT LINES 39
5.3 INCREASE RESOURCES FOR EXTERNAL STANDARDIZATION 39
5.4 STANDARDIZE APPROVAL OF VENDORS 40

6. CONCLUSION 41

6.1 RECOMMENDATIONS FOR FURTHER RESEARCH 44

7. REFERENCES 45

8. APPENDICES 49

8.1 APPENDIX 1: INTERVIEW GUIDE 49
8.2 APPENDIX 2: INTERVIEWEE LIST 50

List of Figures

Figure 1 - Hydrogen Embrittlement due to CP [28] 12
Figure 2 - HIC Conditions [13] 13
Figure 3 - Intergranular fracture due to Hydrogen Embrittlement [29] 13
Figure 4 - Factors Contributing to Cost Escalations 21
Figure 5 - Excerpt from Supplier Variation of Specification 26
Figure 6 - Price Development Bolt 1 26
Figure 7 - Price Development Nut 1 27
Figure 8 - Price Development Nut 2 27
Figure 9 - Distribution of Metallurgists in the Supply Chain 30
Figure 10 - Risk Event Graph [48] 34
Figure 11 - Comparison of Cost and Requirement Flow, Subsea vs. Aviation 36
Figure 12 - NASA Procurement and Documentation Requirements [53] 37
Figure 13 - Modular Spare Part Design [21] 38

List of Tables

Table 1 - Applicable Standards for LAS Subsea Fasteners 5
Table 2 - Maximum Hardness Requirements by Standard 6
Table 3 - Price Driving Factors of Customer Specific Requirements 22

Acknowledgements

I would like to thank Nils Joar Steinsund from GE Ifokus for proposing the orginal ideas for the subject for this thesis. Your frustration for the lack of standardization and a lack of common sense in the industry made me want to dig deep into the material to discover why standardization is far more complicated than it seem at the first glance.

Thanks to my former colleagues at GE Oil & Gas in Stavanger for providing essential data.

Thank you to Vebjørn Andresen from DNV GL for providing essential information about the challenges for fasteners for subsea use, and the perspectives from outside of the supply chain. Your knowledge and insights helped me discover important factors for the use of standardization, and for providing important discussions on the relationship between standardization and ensuring consistent material quality. Thank you Hans Christian Ly from Aker Solutions for providing a few hours of your busy schedule to contribute to this thesis from a Service Supplier's perspective.

A special thanks to professor Petter Osmundsen at the University of Stavanger for being willing to supervise me throughout the thesis. Your enthusiasm for the subject served as an inspiration. Thanks for guiding me on the right track for completing the thesis, and for sharing your experience in academic writing.

Thanks to Paul Meldahl from Statoil for providing important contact information within the company, and for discussing the topic of my thesis with your colleagues.

Last, a special thanks to my classmates for the discussions we had at INDØKS-brakka. To Aina, Monica, Helle, Reidar, Steffen, Truls, André, Ronny, Terje and Ingrid for sticking together even when the great weather on the outside made the indoors at the university the least desirable place to be in the Stavanger region.

Abbreviations and Acronyms

Abbreviations and acronyms used in the report are listed below in alphabetical order:

API	American Petroleum Institute
ASTM	American Society for Testing and Materials
COC	Certificate of Conformity
CP	Cathodic Protection
CRA	Corrosion-Resistant Alloy
HB	Brinell hardness
HISC	Hydrogen Induced Stress Cracking
HRC	Rockwell hardness C Scale
IMR	Inspection, Maintenance and Repair
IOGP	The International Association of Oil & Gas Producers
ISO	International Standardization Organization
ITP	Inspection and Test Plan
JIP	Joint Industry Project
KPI	Key Performance Indicator
LAS	Low Alloy Steel
MPS	Manufacturing Procedure Specification
NCS	Norwegian continental shelf
NDT	Non-destructive testing
NORSOK	The Competitive Standing of the Norwegian Offshore sector
NPD	Norwegian Petroleum Directorate
O&G	Oil & Gas
OEM	Original Equipment Manufacturer
PMI	Positive Material Identification
PSA	Petroleum Safety Authority
SPS	Subsea Production Systems
TR	Technical Requirement

Definitions

Audit: A systematic, independent and documented process to verify that a company has the capability to manufacture fasteners with documented and controlled processes that meet the requirements of the applicable specifications.

Approved Manufacturer: A manufacturer that has passed an audit intended to verify that a company has the manufacturing capability and implemented quality management system with controlled processes that will ensure that products meet the requirements of applicable specifications.

Bolt: Externally threaded fastener with head

Certificate of Conformance (COC): A document signed by the fastener supplier to confirm that the product has met the requirements of the relevant specification(s), contractual requirements and any other applicable regulations.

Cathodic Protection (CP): System utilized to control corrosion of a metal by using it as the cathode of an electrode chemical cell containing both a cathode and anode, where the anode is usually of Aluminum or Zink type.

Fastener: A metallic screw, nut, bolt, or stud having external or internal threads.

Lot: Fasteners produced by same technique from the same heat or cast of material, of same prior condition, same size and subject to same heat treatment.

Non-destructive testing (NDT): Visual inspection, ultrasonic testing, magnetic particle testing, penetrant testing or other non-destructive test methods for revealing defects.

Nut: Internally threaded fasteners for use with the bolts specified above.

HISC: Hydrogen Induced Stress Cracking due to a combination of load and hydrogen embrittlement (HE) caused by intrusion of atomic hydrogen.

1. Introduction

The purpose of this thesis is to investigate the cost implications of customer specific requirements used by the major companies on the Norwegian Continental Shelf (NCS), instead of using common standards. The focus is on fasteners used for Subsea Production Systems (SPS). Subsequently, findings are discussed on how they can be relevant for other types of equipment used in the subsea industry.

All the fasteners discussed are intended for use on SPS on the NCS. Fasteners in this thesis include threaded nuts and bolts between 6mm and 2.5inch made from low alloy steels (LAS), which are the main bulk of fasteners used on the NCS [1].

When the oil price started plunging mid-2014, the margins for the companies operating in the Oil & Gas sector were significantly reduced. The falling price, and the subsequent cut in the oil companies' investment budgets, has forced the subsea industry to reassess what counts as best practice in the manufacturing of subsea equipment [2]. Even before the drastic decrease in the oil price started, some of the major companies operating on the NCS had introduced efforts to reduce the ever-increasing costs of operations [3]. For now, the majority of proposed new developments on the NCS are based on subsea solutions. However, the increasing costs for subsea equipment has led to the development of several alternatives that may prove to be the beginning of the end of the subsea era if the cost escalations are not handled. One of these proposed alternatives is the «Subsea on a Stick»-concept, referred to by some as the "subsea killer"[4].

Drastically falling oil price is nothing new to the industry. In the 1980's, the low oil price challenged the industry, and eventually undermined the economics of large gravity base concrete giants on the NCS, which had been dominant for developments such as Gullfaks, Statfjord, Sleipner and Troll. The oil companies strived to cut costs of developing and operating offshore fields [5], and eventually the oil price reduction turned out to be the factor that led to the break-through for subsea production systems on the NCS [6].

In the early 1980's, the first design of a diver less system was installed by Elf (Total) on North East Frigg [7]. Some years later, the East Frigg development became the first North Sea field to be produced entirely without surface installations [8]. This is by many considered to be the start of the subsea era on the NCS. Since then, the subsea technology on the NCS has moved forward in quantum leaps [9]. The development of the subsea technology has contributed to production from many fields that were previously considered uneconomical. However, the chase for producing oil from fields with longer step-out, deeper waters and harsher environments has come at a cost. From year 2003 until today, the cost for subsea production systems has doubled. This price development is not sustainable for the industry [10].

Subsea equipment has to withstand some of the most challenging environments on earth. With high reservoir pressures, hydrogen induced problems, exposure to production fluids and permanent soaking in salt water, the requirements for ensuring equipment integrity is high. Adding the high costs for replacement of parts and potentially devastating environmental impacts of an oil spill, the industry has accepted high costs for the equipment. This has especially been true for prolonged periods of high oil price. Globally today, over 70% of the wells in deep water developments that are either in service or committed are subsea production units [9], making the need for cost effective solutions and standardization greater than ever before.

Remote operation of fields leads to some major challenges. This is especially true for IMR operations, and together with large costs associated with possible prolonged production shutdown, the equipment costs may become very small compared to the costs of a potential failure. Even with the harsh environment and the extreme requirements for equipment integrity, there are a lot of discussions in the industry about the necessity and the added safety effect of many of the customer specific requirements that are in use in the industry today. The subsea industry has acquired a culture for creating tailor made solutions, instead of using already available components where form, fit and function is identical. With the development of the Subsea factories, the amount of equipment placed on the seabed will increase significantly. This will increase the importance of keeping costs down by standardizing components and requirements.

My interest for the topic arose after working in the industry, and experiencing first-hand how difficult it is to get the job done when the requirements are working against you. Instead of helping to find a simple solution to a job that has been done many times before, requirements tend to create a barrier that prevents simple and efficient solutions.

Other industries, such as aviation and car manufacturing, have gone through the standardization process already with success. In contrast, the subsea industry seem to have fallen far behind. Another industry that most people seldom refer to when looking for cost savings, is the space industry. Just as the subsea industry, the space industry relies on low volume production with extremely high demands for integrity, and still has to stay within budget. This thesis gives a brief introduction to what space and aviation do differently from the subsea industry, and suggest possible learnings that can be implemented in the subsea industry.

The first idea for the subject of this thesis started with an article discussing the 27 shades of yellow paint for subsea structures that FMC Technologies had in their specifications [11]. After discussions with GE Oil & Gas in Stavanger and professor Petter Osmundsen at the University of Stavanger, a study of the cost effects of using customer specific requirements for fasteners was chosen since these were believed to be some of the few parts for subsea equipment where cost effects are measurable and comparable.

The research questions this thesis will discuss is as follows:

1. **What cost driving factors arise as the oil companies add company specific requirements instead of using the common standards for fasteners for subsea equipment on the Norwegian Continental Shelf?**
2. **What factors contribute to the reluctance to use common standards?**

This thesis will also seek to recommend practices for the subsea industry in order to mitigate cost escalations for fastener procurement.

1.1 Limitations

This thesis only investigates the cost effects of using additional specifications on top of already existing common industry standard. Fasteners used for the purpose of this thesis are limited to low alloy steel fasteners, within specification ASTM A193, ASTM A194 and ASTM A320 for use under normal operating conditions on subsea production systems on the NCS. This excludes fasteners for arctic conditions, and fasteners of all other materials such as Titanium, Alloy 625 and other CRAs. The included size of fasteners range from a diameter of 6mm (NORSOK minimum) to 2,5inch (Maximum size for ASTM A320 L7).

2. Review of Literature

2.1 An Introduction to Standards for Subsea Fasteners

Fasteners for subsea applications follow a wide variety of standards. The bulk of bolts used on the NCS are manufactured from LAS, which are prone to hydrogen related failures due to the need for cathodic protection for corrosion protection [12]. The hydrogen related problems related to the subsea use leads to the need for supplemental requirements to some of the commonly used standards in order to mitigate failures.

For the specifications of fasteners produced from LAS for SPS, a wide variety of standards is used. These standards include among others:

Table 1 - Applicable Standards for LAS Subsea Fasteners

Specification	Description
ASTM A193	Specification for Alloy-Steel and Stainless Steel Bolting Materials for High- Temperature Service.
ASTM A194	Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service.
ASTM A320	Alloy steel bolting materials for low temperature service
ASTM A370	Mechanical testing of steel products
TR3101	Bolting Requirements, Statoil Technical requirement
API 20E	Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries.
ISO 898	Mechanical properties of fasteners made of carbon steel and alloy steel
DNV 2008-1656	JIP - Guideline for Specification and Design and Assembly of Offshore Bolted Joints
ASTM A 354	Quenched and tempered alloy steel bolts, studs and other externally threaded fasteners.
ISO 13628-1 Section 6.4	Design and operation of subsea production systems - Part 1: General requirements and recommendations

The most important factor influencing the susceptibility for hydrogen related failures is the hardness of the material [13]. Hardness testing of steel can be performed through non-destructive testing (NDT), where macroindentation test are preferred. The most commonly adopted standards applicable for low alloy steel for subsea applications allow both Brinell Hardness Test (HB) and Rockwell Hardness C-scale (HRC) testing, where Brinell is the preferred method in Europe and Rockwell is the preferred method in the US. Hydrogen induced problems in the subsea environment will be discussed further in section 2.3.

According to Brahimi [13], steel fasteners with a specified hardness below 39 HRC normally have no significant susceptibility to hydrogen embrittlement failure. This means they can tolerate the presence of hydrogen from the cathodic protection system without any delayed degradation of their mechanical strength. This assumption requires that the fasteners were produced by well-controlled manufacturing processes using raw material of sufficient quality. This implies that the common standards for specification of subsea fasteners use lower limits than necessary in order to mitigate possible failures in the production processes.

The maximum allowed hardness of the material varies between the standards according to the following table;

Table 2 - Maximum Hardness Requirements by Standard

Standard	Maximum Allowed Hardness
NORSOK M-001 Rev. 5 ISO 13628 (general material)	328 HB / 35 HRC
API Spec 20E ISO 10423	321 HB / 34 HRC
NORSOK M-001 Rev. 4	300 HB / 32 HRC
ISO 13628-1 6.4.1 Bolting Materials	293 HB / 32 HRC

NOTE: There is no direct relation between the results of the Brinell-tests and the Rockwell test, this can be observed where the old revision of the M-001 specifies 300 HB maximum, and the ISO 13628-1 specifies 293 HB maximum, while both standards specify 32HRC maximum.

2.1.1 The NORSOK Standards

The development of the NORSOK standards started in 1993 when the Norwegian Minister of Industry, Finn Kristensen, established the Development and Production Forum for the Norwegian Petroleum Sector [5]. Just as the situation today, the oil price dropped and costs were rising, resulting in companies struggling for survival.

The NORSOK standards were developed with two main objectives in mind [14];

- A 40-50 percent reduction in cost and lead time based on 1993 best practice
- To maintain the position for the NSC as one of the safest and most environmentally friendly oil industries in the world.

Even before the launch of the NORSOK initiative, the three Norwegian oil companies Statoil, Norsk Hydro and Saga Petroleum had conceived a Joint Industry Project (JIP) for the development of common standards. The work in the NORSOK standardization group was based on the work already done by the three companies, but now other oil companies and suppliers were invited in on a voluntary basis, all covering their own costs. The purpose was to develop a set of common standards that could replace existing company specifications.

When the NORSOK initiative took on to write the specifications, they were fueled by a local industry that was frustrated of too many company- and project specific requirements in use. The industry in Norway saw the gaps in the existing standards and a united industry supported the standardization efforts [15].

NORSOK was first launched with 88 standards where the ultimate goal was to phase out the NORSOK-standards as soon as the ISO standards covered the same areas as the national standards [14]. Companies operating in the North Sea, both UK sector and NCS, met with the Americans during the development of the ISO standard in order to create a single, world-wide standard for subsea equipment. The objective was to ensure that available resources within the industry were to be used most effectively, and their slogan was "Do it once and do it globally!" [14]. In hindsight, it can claimed that the internationalization efforts for the subsea standards have failed. Over twenty years later, the industry still operate with a large number of company specific standards, national standards, and even several ISO standards for the same category of equipment.

The current NORSOK standards covering fasteners for subsea use is the M-001 materials selection, section 5.11.3. Current version is Revision 5, launched September 2014, 10(!) years after the previous revision.

The NORSOK standards are not official standards, but a set of industry standards developed by and for the Norwegian industry [15]. An objective from the contributors is to avoid development of new NORSOK standards where the standardization needs can be covered by international standards work, and that the NORSOK standards should eventually cover additional national Norwegian requirements only [16]. In order to increase the validity of the NORSOK standards, the NORSOK owners are once again launching a review of all standards according to the following criteria [17]:

- Are NORSOK standards cost-effective?
- How may NORSOK standards contribute to improved competitiveness for Norwegian petroleum industry?
- How may NORSOK standards contribute to ensure a satisfactory level of safety on the NCS?
- Are there international standards that can replace NORSOK standards, or alternatively: Can NORSOK standards become "internationalized"?

2.2 Standardization

Fasteners, material selection, documentation requirements, pipe dimensions and threads are among the most basic parts for standardization. These factors will in most cases not put constraints on technology advancement or limit the operator's opportunity to apply an optimized design for a specific case. Rigid requirements for compliance to common standards for the mentioned basic components will not impede the development of new technology, whilst standardizing general arrangements of a system of components may do so [6]. The lowest level of standardization is the standardization of material choice, paint specifications, inspection criteria etc. The next level is the component level including valves, actuators, connectors and sensors. The top level of standardization is the assembled components of the X-mas Tree, Manifolds or tie-in systems [18].

The term standardization is widely used in several industries, and some seem to believe that standardization is the easiest way to achieve cost reductions in all situations. Efforts to improve the effects of standardization are components of the three: process, technology and resources. Standardization and the effects of standardization consist of a large net of interacting variables. The available standards may not necessarily be the best fit for a single project, but from a holistic perspective, the use of standards will lower the overall cost for the industry. This means that there is a large potential value gain by driving standardization across the larger processes in which the standards apply, and by developing means of measuring the impact of the standards [19].

Even if standardization is a keyword in most discussions on cost reductions for the subsea industry, a "one size fits all" solutions does not necessarily need to be a good solution for the complex operating conditions of a subsea field. However, a lot of effort should be put into identifying how the companies with their current specifications can work smarter together.

A JIP for standardization of forgings for subsea use has already been initiated [20]. This project will look into the material requirements, metallurgy and inspection requirements, and will provide manufacturers the ability to stock raw materials. If this turns out to be a success, standardization of fasteners should be the next step. Fasteners are by their nature ideal for mass production. The application range for a single fastener to be used for a wide variety of equipment will allow better interchangeability of parts between projects, and thus promote efficiency in the supply chain. Standardized selection of fasteners will give the manufacturers the ability to increase volumes for a limited number of different fasteners. Consequently, harvesting the benefits of scale for a low number of different fasteners instead of a wide use of low-volume production series. Just as for other components, repeating processes with standardized operations makes people know what they are doing, and this repeatability brings knowledge and confidence on the product performance.

To be able to utilize the full effect of using common industry standards, the users need to commit to the standards and seek to understand and measure the added business value from the standardization [19]. The design process is always a trade-off between operational requirements and the logistics requirements. Interchangeability is one of the focus areas for standardization in the aviation industry, and this is designed into the products for early phases in the product development phase. Standardized parts that can be used in many different locations, and for many different end-customers, is clearly more cost effective than designing different parts to similar tasks, where the variation in functional requirements is insignificant [21].

2.2.1 The Value of Standardization

A factor leading to increased business value through use of common standards is the increased regional availability of parts, since the same part numbers can serve more customers with less warehouse stock. Standardizing parts in product lines, also known as commonality of parts, promotes economies of scale and savings through part interchangeability.

The major advantages of standardization include [6]:

- Reduced number of spare parts
- Interchangeability of parts between projects
- Reduced lead time
- Increased reliability due to familiarity with product
- Increased safety
- More accurate cost and time estimates
- Benefits of scale for mass production

In addition, identifying of areas where parts that are similar in form, fit and function can be standardized, and thus provide increased flexibility through warehouse optimization and reduced lead times [21].

2.2.2 Standardization Challenges

Even if the companies are aware of the value of standardization, most fall far short of their goals of using common parts [22]. Companies often give too much power to individual product managers, who are incentivized to make decisions in the interests of their own products, even if those decisions create divergence that hurts overall profitability [22]. In other words, the companies needs to consider fastener selection at a strategic level, rather on the project specific level.

2.2.3 Previous Standardization Initiatives in the Subsea Industry

The subsea industry has since the early beginning looked to standardization as the way towards making subsea developments cost effective solutions for field developments on the NCS. Sandhaugen and Lindland [6] published a SPE paper less than 10 years after the installation of Statoil's first subsea development at Gullfaks. The introduction states;

> “A dominant characteristic of today’s oil industry is the frequent and unpredictable fluctuations in the oil & gas prices. This is forcing the industry to lower its development and operations costs. As important is the ability to maintain costs at a low level regardless of transitory high or forecast of increasing oil and gas prices. Additionally, profitable development of marginal fields necessitates reduced costs. Standardisation contributes to this through reduced equipment, manpower and operations costs.” SPE 25066: Development and Standardisation: Challenge or Contradiction? - 1992

This introduction might just as well have been used for this thesis, over twenty years later. The repeated finding from several published papers on the need for subsea standardization is the belief that “Significant cost reduction can be achieved by standardization” [6, 14, 15].

An OTC paper from 1996 by representatives from Statoil, Saga Petroleum, Hydro and the Norwegian Technological Standards Institution stated; “The rising cost of offshore development and reduction in oil prices required new initiatives for the business to survive. Therefore, the Norwegian oil industry has, as a part of the NORSOK initiative, developed a set of new industry standards to replace individual company specifications.” [15]. This shows how once again, the hunt for standardization was related to oil price reductions.

Since the launch of the NORSOK standards, there have been several other efforts in order to harness the cost escalations in the subsea industry. Most of these standardization initiatives has followed periods of low oil price. However, when the oil price rise back up, the industry as a whole is quick to forget and once again starts adding additional price driving requirements and procedures.

2.3 Bolting technology – an interdisciplinary subject

Many of the bolted connections used in the subsea industry are critical parts of the system. Failures of such parts have found to be a major cause for leaks on offshore installations [23]. The fasteners used for critical applications in subsea production systems represent a major challenge in terms of material selection, quality control, traceability and documentation in order to ensure the required performance and integrity to avoid costly and environmentally devastating failures [12]. However, the design process for the bolted connections in the industry is an area that will require substantial work in order to coordinate the existing standards and practices among the companies. The offshore industry has not been consistent in their practices regarding the design and specification of bolted connections, in great contrast to welding, where process control and formal requirements are in place and are being strictly enforced [1]. Both welded and bolted connections are critical for system integrity, thus it is interesting how differently these two material joining technologies have been prioritized.

LAS fasteners rely on Cathodic Protection (CP) in order to prevent corrosion. Cathodic Protection is according to ISO 8044 "*electrochemical protection by decreasing the corrosion potential to a level at which the corrosion rate of the metal is significantly reduced*". This is achieved by using anodes and ensuring electrical continuity between the anodes and all parts that are to be protected. For a galvanic anode CP system, the protection potential for the main part of the design life will be in the range of -0.90 to -1.05V. A byproduct of the CP system is the formation of atomic hydrogen, (illustrated in Figure 1) the smallest of all atoms, at the metal surface. Within the potential range for the most common Aluminum and Zink based anodes, the production of hydrogen increases exponentially towards the negative potential limit [24].

With the major challenges fasteners used for critical applications on Subsea Production Systems represent, production processes for these should be equivalent to other critical components like pressure containing and primary load bearing components [25]. This also includes means of assembly, and qualification of the company and personnel performing the assembly. The main consideration for the fastener integrity is the mechanical properties of the fastener material and the susceptibility to hydrogen cracking effects (Hydrogen Embrittlement) [26]. The maximum hardness of the material is the single most critical factor to prevent this problem.

The bolts in this thesis are limited to ASTM A320 and A193 standards, and for these the following apply:

ASTM A193 Grade B7 is a bolting specification for medium-high temperature service. It is a heat treated chromium molybdenum steel and is considered suitable for applications up to 450°C (840°F). ASTM A320 L7 has the same chemical & physical properties as A193 B7, with additional Charpy V Notch (CVN) tests taken at -101°C (-150°F) for low temperature service [27]. Both are manufactured from AISI 4140 or 4142 steels. Due to the extra charpy tests specified for the L7 material quality, B7 should be excluded and A320 L7 should be required as the fastener material for subsea applications [1].

2.3.1 Failure Mechanisms for Bolts

There are several failure mechanisms leading to the failure of bolts for subsea use. These mechanisms may be either mechanical from overloading; fatigue or galling, corrosion driven, or it can be due to a combination of both.

Hydrogen Related Failures

When a LAS high strength fastener is tensile stressed, as is the case with a fastener that is under load from tightening, the stress causes atomic hydrogen within the steel to diffuse (move) to the location of greatest stress. In most cases, this is at the first engaged thread or at the fillet under the head of a bolt. As increasingly higher concentrations of hydrogen collect at this location, the steel gradually becomes more brittle. Eventually, the excessive concentration of stress and hydrogen in one location initiates a crack. The brittle crack continues to grow as hydrogen moves to follow the tip of the progressing crack, until the fastener is overloaded and finally ruptures. This hydrogen damage mechanism can cause the fastener to fail at a stress that is significantly lower than the calculated strength of the fastener [13].

In order to mitigate the possibilities of hydrogen related failures, some standards have introduced maximum hardness requirements. These material properties can be measured by NDT methods, such as macroindentation where limits between 31HRC and 35 HRC are widely used. However, these values are largely unsupported by data, and have been adopted primarily as a precautious measure against manufacturing errors that could make the material significantly more susceptible than it should be [13]. In most cases, the root cause of hydrogen related fastener failures are linked to improper quenching and tempering processes. Consequences of this include higher than expected hardness, which in turn makes the material more susceptible to hydrogen embrittlement. Therefore, it is critical to ensure that the heat treatment process for producing fasteners need to satisfy the requirements specified in material standards regarding hardness and other material properties.

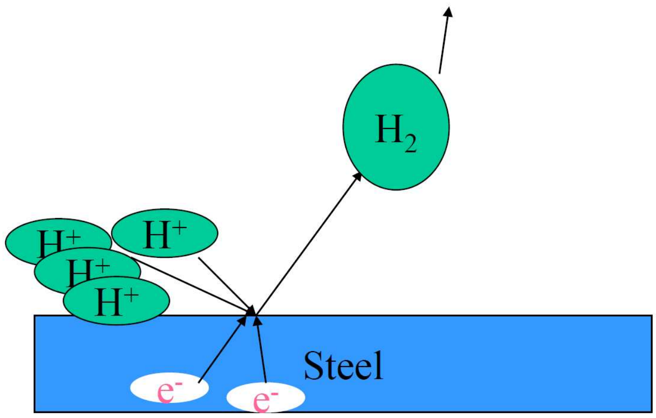

Figure 1 - Hydrogen Embrittlement due to CP [28]

Hydrogen embrittlement has been studied for decades, but still the industry is struggling to translate the knowledge into useable standards and know-how. Circumstances are further complicated by standards that are sometimes inadequate and at other times unnecessarily strict; and even in some cases they are both at the same time. Inconsistencies and even contradictions in fastener industry standards have led to much confusion and many preventable fastener failures [13]. This confusion clearly exists in the subsea industry, where the different standards have not been able to agree on what hardness should be maximum (see Table 2), and how this should be documented.

The environment and operating conditions in the subsea world exhibits all of the necessary conditions for occurrence of hydrogen-induced problems for the fasteners. These challenges leads to the need for supplemental requirements to existing standards (such as ASTM A320), in order to ensure sufficient resistance against hydrogen related problems. The conditions related to hydrogen embrittlement failure are illustrated in Figure 2.

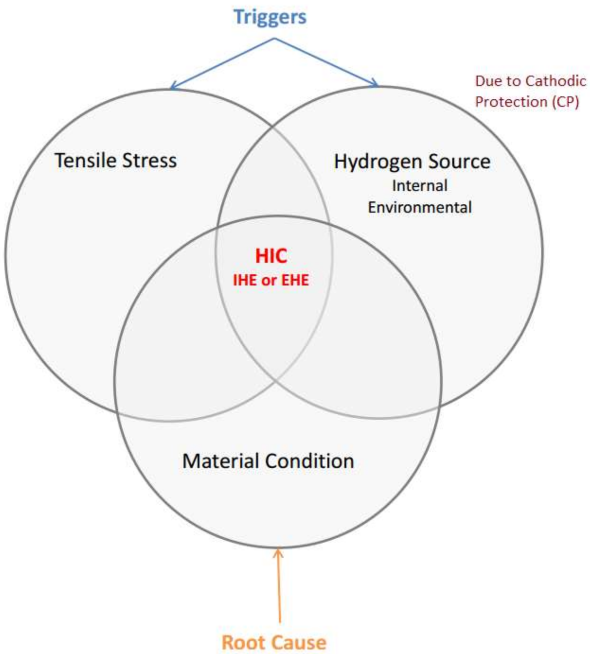

Figure 2 - HIC Conditions [13]

1. Susceptible steel – Due to LAS
2. Stress/Applied load – From bolt tension
3. Atomic Hydrogen – Result of CP system for subsea structures.

The Hydrogen Embrittlement leads to brittle intergranular failure, illustrated by Figure 3.

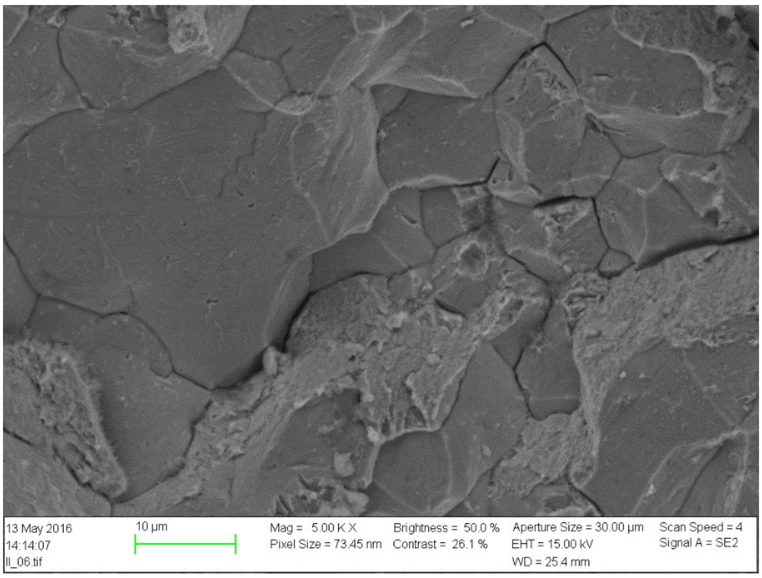

Figure 3 - Intergranular fracture due to Hydrogen Embrittlement [29]

There are several other failure modes for subsea fasteners that are not related to hydrogen embrittlement. These include among others:

General Corrosion

Lack of contact with the Cathodic Protection system.

Galling

A form of adhesive wear from the sliding of two surfaces relative to each other. Prevented by the correct specification of threads.

Fatigue

May be due to manufacturing defects.

Overloading

Due to wrong installation.

- Over torque
- Wrong lubrication of threads
- Improper surface coating

Other Common Failure Methods for Fasteners [25]

- Tension failure of studs
- Tension failure of nut threads
- Tension failure of stud threads

The abovementioned bolt failure mechanisms are mostly governed by existing standards. However, according to Andresen from DNV GL, the installation procedures that may contribute to overloading of fasteners during assembly are not sufficiently covered in existing standards.

2.4 Previous Research on Effects of Standardization in O&G

OG21 TTA4 Report

There is very little research to be found on the cost saving effects of standardization of requirements for subsea applications on the NCS. The most important research the recent years is done by the OG21 workgroup. OG21 is a cooperation between upstream companies, universities, research institutions, suppliers and governmental organization started to coordinate and develop a national strategy for technology development in Norway.

The TTA4 report from OG21 has identified the complexity of the standards in today's form, as a major barrier for the use of common standards. Combined with additional technical requirements from the operator and system supplier, the fastener manufacturer (sub-supplier) spends excessive amounts of engineering hours on technical clarifications and possibly conflicting requirements.

Key improvements are identified to be [30]:

- Reducing the complexity of specifications
- Reduce technical requirements
- Review requirements with suppliers/sub-suppliers to identify required changes

Proposed mitigation of the problem is to challenge the background for the requirements. Many of the requirements arise from different projects allowing the engineers to create new specifications instead of using existing requirements. This problem may also be related to the engineers being allowed to use a large variety of fasteners instead of having to design with a limited number of available fasteners from an approved parts list.

In addition, the OG21 work group addresses the simplification of the qualification of equipment as an important improvement area. By following common qualification requirements for standard components such as fasteners, the companies in the industry will be able to utilize work performed by others. Today, the sub-suppliers use large amounts of resources in order to prove for their customers repeatedly that their manufacturing processes are of the required standards.

IOGP Report 500

The IOGP 500 [31] report on standardizing activities in the petroleum industry finds that the participating companies use almost four times more resources on management and development of their own standards, than for external standardization activities.

Other Research

A project for assessing the difference of price impact between using common standards and company specific standards when building rigs for use in harsh environments found that similar safety could be achieved at about half the cost through a risk-based selection of standards [32].

3. Methodology

For this thesis, the case-study methodology was used. The reason for using the case study analysis is the method's applicability to real-life problems and the accessibility through the use of a written report. The case study results relate directly to the reader's everyday experience, and will help the reader obtain an understanding of rather complex real-life situations [33].

3.1 The Case Study Method

The definition of the case study is as proposed by Yin [34]: "A case study is an empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident. " For this thesis, the nature of the available data creates a large number of unknowns due to the business sensitivity of discussing price development. The objective of the thesis is not to find a specific measurable number for the actual cost of the way things are done in the industry today, but rather to investigate which factors that are contributing to increased cost, and why the industry is not able to use a set of common industry standards instead of using customer specific standards.

The Case Study Method is a qualitative research method. According to Foster and Robson [35], the qualitative method can be used to answer questions to "why". The question to "why" has been important for this research, since the goal has been to investigate why with 20 years of standardization initiatives in the subsea industry, customer specific requirements are still used by all the major companies operating on the NCS.

In general a Case Study is performed when either the "how" and "why" questions are applicable, the investigator has little control over events, and the focus is on a phenomenon within a real-life context [36]. A case study is most commonly based on evidence from the Six Sources of Evidence; documentation, archival records, interviews, direct observations, participant observations and physical artifacts.

"Case Study Research is an inquiry that focuses on describing, understanding, predicting, and/or controlling the individual."
[37]

As this is an academic case study, the focus is on an individual or a small group, with the objective of producing a detailed but non-generalized report based on literature study and the data collected.

3.2 Research Method

According to Streb [38], the exploratory case study investigates distinct phenomena characterized by a lack of detailed preliminary research, and is often applied as a preliminary step of an overall causal or explanatory research design exploring a relatively new field of scientific investigation. With the limited previous research found on the effects of standardization in the subsea industry, the exploratory case study becomes applicable for this thesis.

The analysis of the provided data in this case study is based on a contextual analysis of a rather limited number of events. The goal has been to describe the relationships between the price development and the introduction of new requirements from the upstream companies. Interviews and statements are collected from suppliers, upstream companies and the verification industry through DNV GL.

The participants for both the in-person interviews and for e-mail interviews are all experienced professionals from the subsea industry. The purpose of the selection of participants and contributors has been to get a wide understanding of how different parts of the industry, with different interest in the subject, see the challenges and the possible cost reducing efforts for fastener specification.

Several articles have been written regarding the need for standardization and many more have been focused on effects of standardization in other comparable industries, such as in the aviation and automobile industries. However, very few of these are addressing the actual price driving factors related to not complying with industry wide standards.

According to Soy [33], case studies can be used to extend experiences or add strength to what is already known through previous research. In this thesis, the limited previous research on standardization initiatives in subsea industry operating on the NCS is used for comparison with how other industries has implemented standardization. An additional goal of the research has also been to look into differences and similarities between the industries, and to get an understanding of how and why other industries has managed to implement common standards.

Due to the business sensitiveness of the pricing of parts between sub-suppliers, service companies and upstream companies, information was not considered to be of enough availability to perform a quantitative analysis.

The research is done both as prospective research through collection of historical price data from the companies, and retrospective looking into previous research, mainly research available from Society of Petroleum Engineers (SPE) databases.

The core businesses of the companies in the case study included:

- Oil & Gas Upstream Companies, operators and customer for subsea production systems. Owne the specifications of requirements related to design, manufacturing etc.
- OEM of subsea production systems: Manufacturing of main components, providing spare parts, performing maintenance on-shore for products.
- Manufacturers of fasteners for subsea applications.

3.2.1 Interview Structure

The interviews used in this thesis are either semi-structured group interviews, or e-mail dialogues. This provides the flexibility that the interviewees need in order to be able to raise questions and concerns in their own words and from their own perspectives. Semi-structured interviews also gives the interviewer the ability to be more involved in focusing the conversation on issues that are considered important for the research project [39]. In interviews, we do not simply find a reproduction or representation of existing knowledge, but rather an interaction about an issue that is part of the knowledge produced in this situation [40].

The goal of the interviews was to get a descriptive understanding of the reasons for the way things are done in the industry today, and to be able to identify the actual problems in the industry. In addition, the interviews are used for triangulation of the data, by giving inputs to how the data should be analyzed. The relatively small number of interviews performed was done in the spirit of Harry Wolcott: “Do less more thoroughly” [41]. The interviews were performed in Norwegian since all participants were Norwegian. This was chosen in order to reduce any chance of misunderstandings due to language barriers. Due to the business sensitiveness of some of the subjects discussed during the interviews, the interviews are included as a summary in the text, with the interview guide attached in the appendix section. The focus group interview featured participants from DNV GL and Aker Solutions. The participants are all among the most experienced professionals in Norway within bolting technology. Since the group interview is well suited for exploratory studies in little known domains [39], the decision was made to rely on the method for this thesis.

3.3 Data Analysis

With the wide range of existing standards, test methods, manufacturing methods and price driving factors influencing the purchasing price of fasteners for low volume use, the data analysis is used to investigate trends, rather than to investigate actual costs. Price varying elements not directly related to the specification of requirements and testing methods include:

- Expedited purchases
- Business to Business price strategy
- Price variations due to overall pricing of frame agreements
- Purchases done with other customer specifications, for other projects

Error sources for the data may be due to wrong data punching from employees, wrong specification used and wrong currency settings. All data are provided from the SAP-software, and may in some cases have been automatically generated.

For the data analysis, all values given in NOK are removed from the data set to avoid inconsistency in NOK/GBP exchange rate. Due to the few samples given in NOK, this makes little impact on the data trends.

The data shows historical prices for several part numbers, where the specifications from the end customer has been changed over time. These are all either nuts or bolts for use on SPS. Note should be taken that all provided prices are priced from bolt manufacturer to equipment manufacturer, thus it is not the price that is charged to the end customer, the Operator Company.

3.4 Biases of the Participants

Most of the participants in this Case study are prone to have some kind of bias for the results of the study. The customer-supplier relationship between the participating oil companies and the oil service companies is the most obvious bias. During my research several occurrences of one part blaming the other for the price escalations in the industry was encountered.

Another important bias that should be considered, is that DNV GL is a provider of certifications and classifications, and may benefit economically from leading JIPs towards implementation of common standards.

Most of the previous research found on experiences with the implementation of NORSOK standards are written by employees of Statoil or companies merged with Statoil from SAGA Petroleum or Norsk Hydro.

These potential biases are handled by using several sources, and comparing the results from the different parties. When there has been any kind of doubt about the validity of the information, the information has been excluded from the research.

3.5 The Goal of the Research

The goal of this thesis is to contribute to bridge the gap between the understanding of engineers and economists in the industry of cost implications arising from the requirements in use, and which requirements need to be in place in order to ensure fastener integrity for subsea use.

4. Results and Discussion

Grethe Moen, Managing director of Petoro made a point out of the 27 different specifications of yellow paint for subsea applications available from FMC Technologies at the OG21 conference in 2015 [11]. The reason for the 27 different shades of yellow, are small differences in the specifications from the oil companies. Even if the function of the product is identical, the functional requirements are not the only specified. Because of the varying customer specifications in addition to the function, identical products with the same function, get different part numbers from the suppliers. Just as for paint, the number of practically identical fasteners with different part numbers in the subsea industry is overwhelming. Oil service companies are quick to blame the oil companies for the large number of specifications in use, but the problems are related to the whole supply chain, and the lack of communication between companies.

4.1 Cost Driving Factors

There is a common understanding in the subsea industry that actions are needed in order to cope with the escalating costs. As the oil price has dropped, industry wide initiatives towards implementation of standards and standard equipment is about to change the industry. As the oil price has plunged, several of the large oil companies have forced their suppliers to cut their prices. This makes it difficult to distinguish which cost reductions are related to standardization, and which are from the short-term market effects.

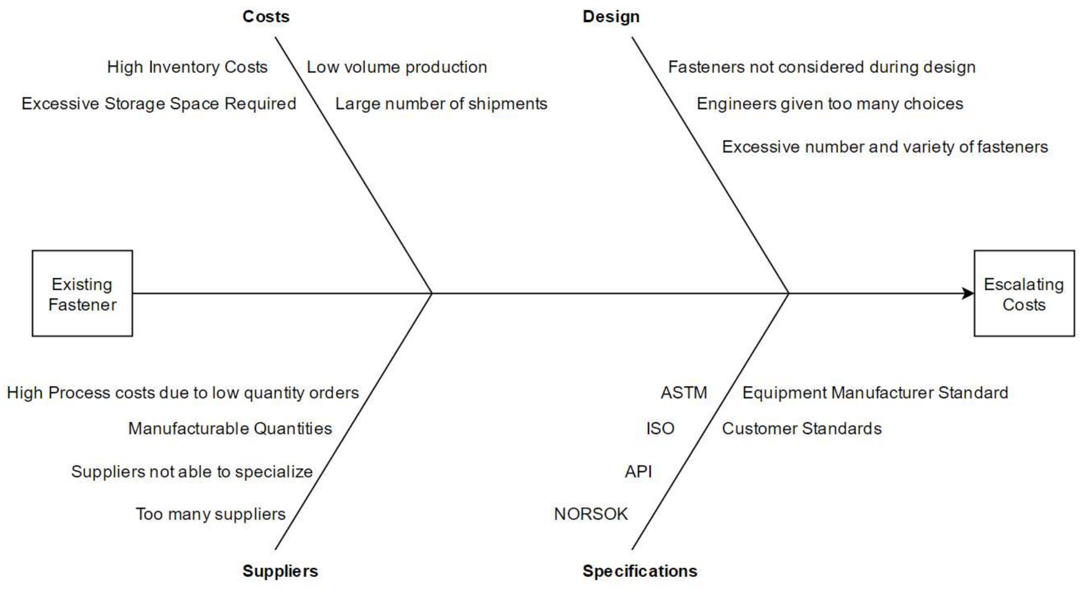

Figure 4 - Factors Contributing to Cost Escalations

Many of the companies in the O&G industry use standards that reference to the common standards. As long as the company specific standards use only few supplementary requirements, standard parts can in most cases be used without adding significant cost [31]. When the company specific requirements use several requirements that are not in line with the referenced standard, cost implications are more eminent. The reason for these costs are mapped in Figure 4 - Factors Contributing to Cost Escalations. In many cases, the costs of upgrading or customizing requirements are not compared to the cost effects [42] of the added requirements. This happens when companies fail to develop and execute an approach to standards that reflect the company's overall strategy and commitment to standards development.

Traditionally for the subsea industry, new systems and processes have been developed by adding more specifications and requirements. The industry has in a limited degree used the capacity in order to reduce costs through technology development requiring less requirements [18].

Table 3 gives an overview of the most important price driving factors that arise from the use of customer specific requirements for fasteners. These factors will be presented and discussed in the following sections accompanied by a discussion of possible solutions.

Table 3 - Price Driving Factors of Customer Specific Requirements

Low production volumes lead to high machining costs
High documentation cost per unit
Increased warehouse cost
Cost for keeping requirements current
Increased lead-time, possibly delaying deliveries
Engineering resources spent for clarifications at the customer
Excessive inventory costs due to many similar parts in inventory
Producers not able to stock raw material
Vague requirements – Resources used for clarification
Change orders when suppliers cannot deliver on time

4.1.1 Low Volume Procurement

The wide use of Customer Specific Requirements drives low volume procurement. The interviewees agree that the usually low volume in each order for fasteners are among the most important price drivers. The biggest spikes in the price data found in the data in Section 4.1.5 is for low volume purchasing, where the cost for expedited delivery and the delivery costs are a large part of the price for each fastener. This can be seen as the cost due to lack of regional availability according to Boas and Crawley [22].

The following costs occur due to low volume procurement:

- **Warehouse Costs**
  - The warehouse at the oil service company needs to keep track of a large number of part numbers of parts that have only small nuances in testing requirements. This requires more storage space in the warehouse and more labor-hours.
- **Shipping Costs.**
  - Larger quantity of bolts would reduce shipping costs.
- **Documentation Costs**
  - Documentation will be practically identical for large batches.
  - Low volume → Increased resources document control/production
- **Machining Costs**
  - Set-up cost for machines used in production is drastically reduced as production quantity rise towards production optimum.
  - The capital costs associated with production tooling and associated machinery cannot be efficiently spread in a low-volume environment, and lead to the methods often becoming prohibitively expensive. With the associated setup-time and production shut down needed in order to create custom specification for manufacturing processes, the costs of low volume production increase rapidly [43].

According to DNV GL/Aker Solutions (Interview 27.05.2016), there is little communication between the suppliers and the customers in the subsea industry concerning optimum production quantities for the manufacturers of fasteners.

In order to achieve the manufacturing conditions specified in some of the customer specific requirements, the suppliers' machines have to be stopped in order to calibrate the equipment. This is a major cost driver in the production process, and have a significant large impact per unit considering the low volumes of fasteners procured in the industry. In addition, for contracts where the equipment manufacturers are paid project wise, there are few incentives to stock large quantities of fasteners that can possibly be made obsolete if the oil companies change their requirements.

4.1.2 Too Many Different Parts in Use

There is a common understanding among the interviewees that the main issue is not the specifications, but rather the procurement strategy and that the engineering departments are allowed to use too many different fasteners. Many describe a culture in some of the subsea companies where the strong partitions of engineers drive through costly solutions. These partitions are often the deciding factor when decisions are made.

In order to cope with this, the industry needs to increase the engineers' compliance with pre-established industry standards [44]. Increased compliance with the standards will contribute to the companies' ability to conduct strategical sourcing. Reducing the number of different fasteners will also contribute to reduced turn-around time for refurbishment of equipment due to increased part interchangeability between projects.

Several interviewees have experienced situations where fastener selection seems to have been given last priority during the design process. Instead of designing the equipment to incorporate standardized fasteners, less available fasteners are chosen. Selection of the most viable fastener is not simply a matter of selecting the most common or versatile items from previous company stock, but rather selecting a product that is widely used in the industry. This can be achieved by starting with people that understand both the technical and the supply chain aspect of the products.

In order to reduce the number of part numbers in use, the subsea industry can learn from NASA and their use of Approved Parts List for fasteners stating [45]; "Fastener reliability begins with the preparation of an approved parts list (APL), consisting of certified parts with proven performance, selected for the appropriate application, and procured only from approved suppliers. To ensure certified quality and reliability, fastener types, and styles should be kept to a minimum, with fasteners obtained from an approved source. Fastener cost can be better controlled by implementing, in the initial phases of a program, a plan of consolidation and centralization of efforts related to fastener selection, receiving inspection, testing, and traceability. "

By using a similar system for the subsea industry, refurbishment/upgrade of existing equipment, turnaround time and cost for refurbishment can be significantly reduced by increasing fastener commonality between systems, which would be promoted through a limited number of fastener types in use.

One of the Equipment Manufacturers found almost 20,000 purchase orders in their systems for bolts during the last five years. This occur due to a combination of purchasing of fasteners for few projects at a time, and a wide variety of customer specific requirements in use. A probable cause for this vast amount of part numbers for fasteners is the lack of focus on costs that has been prevalent in the industry during periods of high oil price. Most project managers and engineers have considered fasteners as the least critical part during the design of the equipment. Instead of choosing from a limited number of available fasteners specified by strategic departments of the companies, engineers and project managers have been given the choice of choosing the fasteners that suits their project without looking at the wider perspective of strategic sourcing.

As already well covered, a gigantic amount of fastener specifications and variations is available. This choice however, comes at a cost that does not seem to have been considered by many. A car or an airplane engineer has most likely been given a lot fewer fasteners to choose from during the design than an engineer designing a subsea X-mas Tree. A cliché to be used would be to claim "this is not rocket science", but even NASA has guidelines to use the least costly and most available fasteners.

4.1.3 Cost of Audits

The OG21 TT4 report identified simplification of qualification as an area where large cost savings are possible. DNV GL have worked with customers in the supply industry where over 150 audits was performed in one year. Each of these audits can last for several days, leading to a continuous qualification process for the supplier, with very little value added from the work done. Each audit takes up resources from both supplier and auditing company, and in total this sums up to large resources. The suppliers are in most cases already approved by other upstream companies, thus most of the audits could have been avoided if the companies utilized common requirements and processes for approval of vendors. This however, relies on the use of common standards between the companies.

API has recently introduced the API Monogram, a voluntary licensing program designed to facilitate the consistent manufacturing of product that conforms to API standards. For this system, API performs the audits and approve the vendors. Development of an equivalent system, but with the additional experiences and recommended practices from the NCS implemented, would reduce the cost for audits, and thus increase the number of suppliers able to compete for each quote.

Regarding the material for the DNV GL recommended ASTM A320 Grade L7, there are only a few suppliers that serve most NCS operators for raw material (Mainly Ovako and Tata Steel). The material quality from these mills has historically not been the problem as they have proved consistent material quality.

Much of the additional audits required are due to a lack of trust that exists between customers and suppliers in the industry. This will be discussed further in Section 4.2.5.

4.1.4 Systems Supplier Providing Additional Requirements

In addition to end customer requirements and industry standards, systems equipment manufacturers provide their own requirements [30]. This leads to potentially conflicting requirements where the sub-suppliers spend excessive amounts of engineering-hours for clarification of ambiguous requirements and for solving issues of conflicting requirements. This also contributes to the equipment having a higher degree of complexity than what is needed, with the subsequent cost increase. When additional requirements are added beyond a certain point, they do little to reduce risks. The additional requirements can even add risk through introduction of more complexity, and limit supply chain efficiency [46]. Figure 5 illustrates the variety of customer specific standards to which a randomly chosen fastener manufacturer (Alca Fasteners) have to comply. Even if the supplier companies are quick to blame the oil companies for the vast amounts of specifications in the industry, six of the eight supplied specifications are Customer Specific Requirements for Oil Service Companies.

Figure 5 - Excerpt from Supplier Variation of Specification

4.1.5 Cost Development for a Selection of Fasteners

All parts covered in the data analysis are by specification from Statoil technical requirements, TR3101. This standard was first established in 2009. The graphs show the development of the purchasing price for the given fasteners for GE Oil & Gas. A large part of the variance is believed to be same part number being used for other customers, thus being according to another customers' specification, where the fastener manufacturer is able to supply from existing stock.

- Statoil TR3101 revision 2 is dated – 09 2010. In order to incorporate for some time for the introduction, the price averages are divided into before and after 01.01.2011.

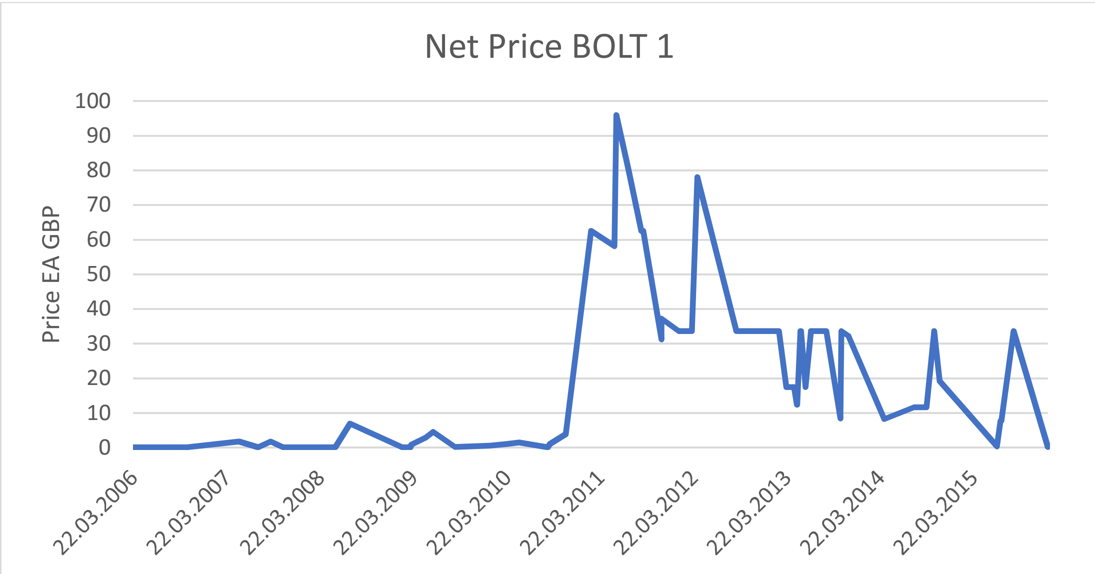

Figure 6 - Price Development Bolt 1

Average before 01.01.2011	GBP 1,23
Average after 01.01.2011	GBP 32,50
Percentage increase	**2547%**
Price minimum	GBP 0,1
Price maximum	GBP 80,16

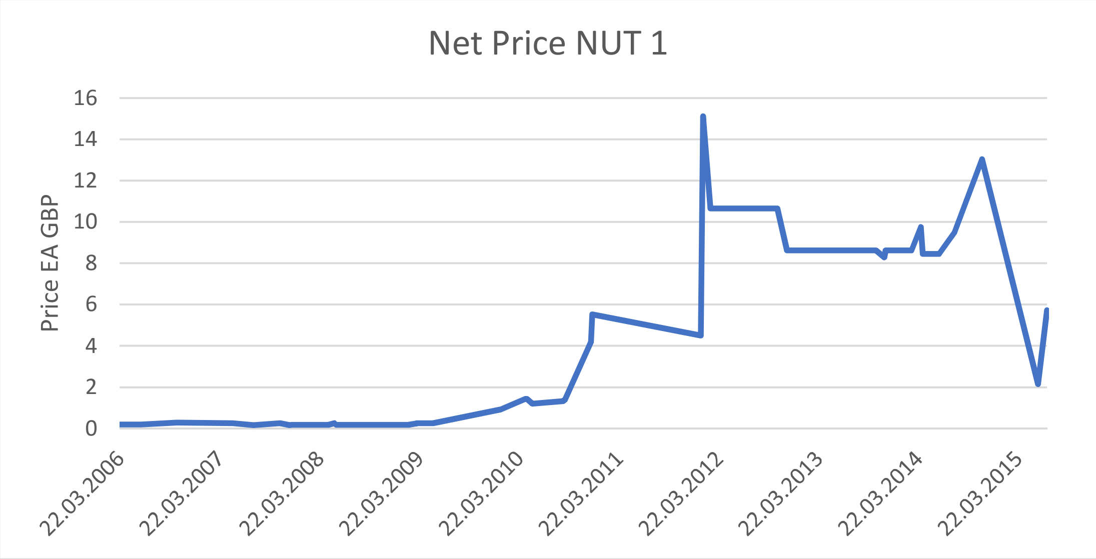

Figure 7 - Price Development Nut 1

Average before 01.01.2011	GBP 0,85
Average after 01.01.2011	GBP 9,00
Percentage increase	**947%**
Price minimum	GBP 0,17
Price maximum	GBP 15,11

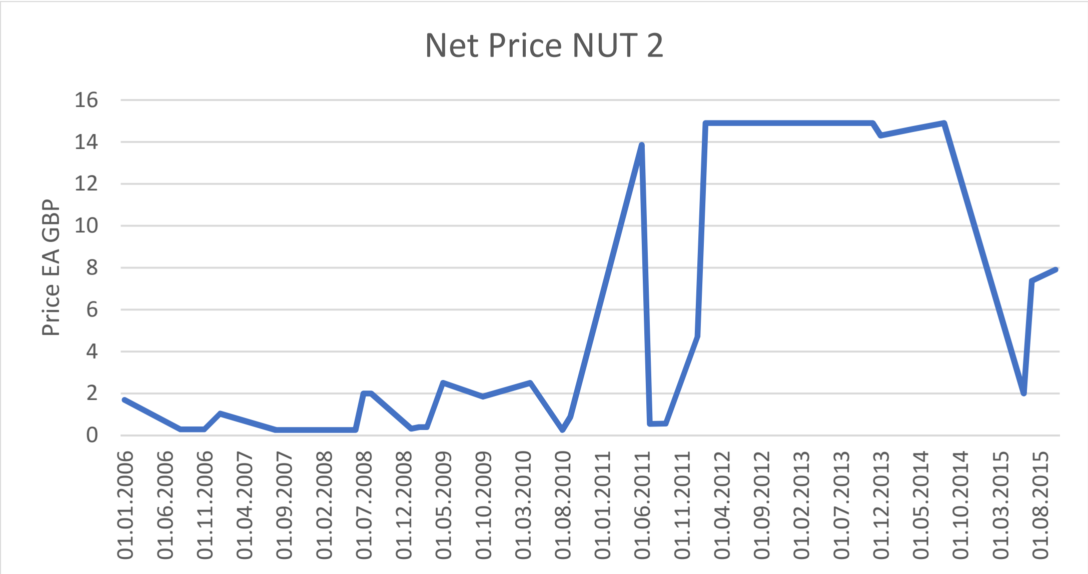

Figure 8 - Price Development Nut 2

Average before 01.01.2011	GBP 1,01
Average after 01.01.2011	GBP 10,89
Percentage increase	**978%**
Price minimum	GBP 0,26
Price maximum	GBP 14,91

The price spike in all the three data sets is related to hydrogen induced failures for M10 socket screws used on transmitter flanges on some of Statoil's X-mas Trees[12]. According to Haldorsen (Statoil, E-mail dialogue), this created a need to replace all the bolts of the same type in use for all Statoil projects after the discovery of hydrogen related failures. This led to billions of NOK in expenditures for the company because of the replacement campaign. The failures were found to be related to HIC, and eventually led to the development of new permanent requirements from the operator, through the TR3101 bolt specification for bolts where CP is used as corrosion protection.

Prior to the introduction of TR3101, there was not sufficient traceability of the fasteners in use (DNV GL/Aker Solutions group interview 27.05.2016). A lot of the price increase is related to the introduction of the required traceability through the supply chain. In addition, manufacturing process control also cost, but with the high costs associated with failures for subsea systems, some costs related to this is considered acceptable. This explains a large portion of the cost increase, but far from all of it. According to some fastener end customers, the high oil price combined with increased requirements may have given suppliers a chance to increase their margins when pricing future fasteners..

OG21 [30] estimates approximately 300 subsea X-mas Trees was installed on the NCS in year 2014, where a normal subsea X-mas Tree incorporates almost 1500 fasteners. In addition to other fasteners used for manifolds and other equipment installed on the seabed. If using an estimate of an average 1000% increase, and a bolt price of 100 NOK, the increase would be around 40 million NOK just for the 300 X-mas Trees in operation. These numbers does not incorporate for large fasteners that would be significantly more expensive. What can be interpreted from the numbers however is the need to consider the alternative costs for each fastener. Even if the price increase seems drastic, the cost of the fasteners becomes small compared to the costs of possibly having to replace fasteners once they are located subsea.

The Interviewees from DNV GL/Aker Solutions believed the first spike is a price shock as the manufacturers discovered that there were requirements for traceability and process control. The increase may at the first glance look like a cost explosion, but DNV GL and Aker Solution (Interview, 27.05.2016) claims that the industry had almost no traceability of the fasteners in use before the incident. The lack of traceability meant that there was no possibility to ensure that the bolts had been manufactured under the same conditions, and thus possessed the same material properties.

One correct market price for fasteners is practically impossible to estimate. The prices that was seen before the revisions of the specifications have proved to be unrealistic since traceability for the fasteners were practically non-existing. The introduction of reasonable traceability and material composition requirements led to a price boost in the market. With the low amount of fasteners that are procured, and with the relative high number of suppliers of fasteners in the market, the suppliers use a lot of time to get familiar with the new requirements.

This in turn means that the price was forced high for a long period afterwards. The subsequent drop in price seen in the data is most likely composed of a chain of events, including producer familiarity with the requirements and tough negotiations from the customer.

During the last years, the LEAN-mentality and other systems based on continuous improvement has been implemented among some of the elements of the supply chain. This is likely to have contributed to cost reductions in the industry.

4.1.6 Cost of Maintaining the Standards

A report by IOGP [31] finds that the 22 companies participating in the survey average with 453 standards each. With the average number of pages being 28, this leads to a total of 200,000 pages for just these 22 companies. This is equivalent to eight stacks of documents from floor to roof in a normal office. If the goals for keeping the standards current are to be achieved, twenty five percent of these need to be revised every year. This is a very large amount of complex and detailed documents.

4.1.7 Effects of the Requirements in Use

The network of requirements that are currently in use are believed to have had an effect (group interview, DNV GL/Aker Solutions 27.01.2016). Since the implementation of the revised TR3101, there is no evidence of any failures related to fasteners in operation. However, there are failures that have occurred during installation of bolts. This shows that TR3101 have had a positive effect for the integrity of fasteners, but the cost increase of over 2500% in long time average increase for some of the fasteners is far more than necessary. The low-period numbers (pre-2011) does not incorporate sufficient traceability. This lack of traceability proved costly for Statoil when a campaign to change out the applicable fasteners took place.

The way that the requirements are forced down through the supply chain today, the suppliers with their limited metallurgical competence (Figure 9 adopted from Hans Chr. Ly, Aker Solutions) may struggle to understand what is to be delivered. The figure illustrates how the oil companies have large materials departments that come up with new requirements. For each step down the supply chain, fewer material experts are employed. According to interviewees, Statoil at one point had around 100 metallurgists. Aker Solutions, the next company in the Supply Chain had approximately 40 metallurgist, while the fastener supplier had none. In the aviation analogy, the Airlines, as the end-customer does in most cases not possess any material experts, but rather rely on the expertise of the equipment manufacturers.

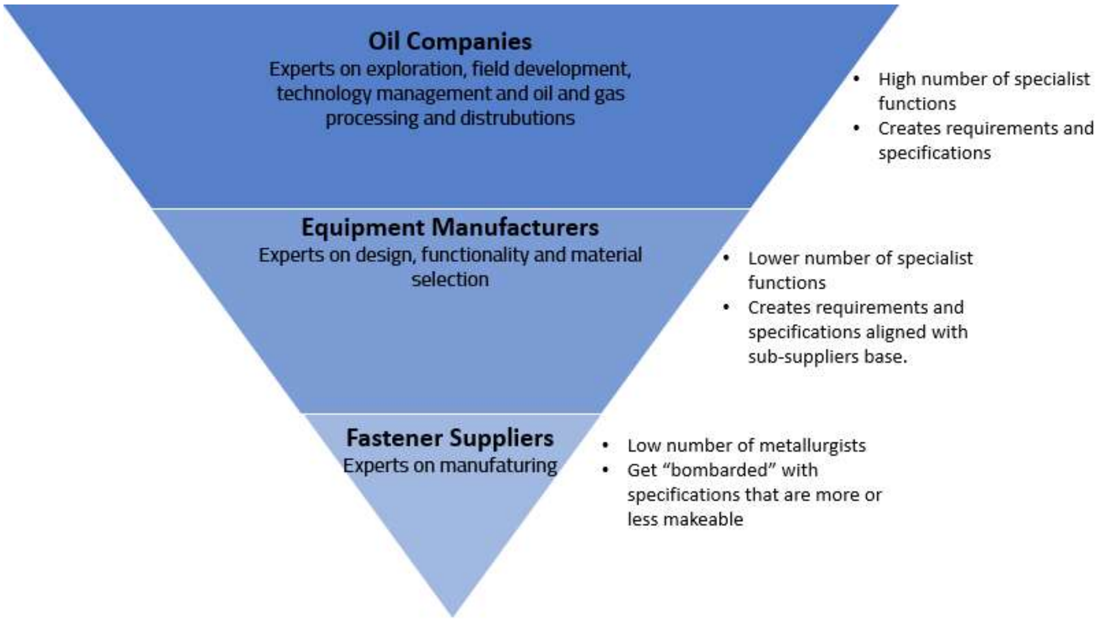

Figure 9 - Distribution of Metallurgists in the Supply Chain

Statoil material experts have experienced the following challenges with fastener manufacturers [12]:

1. Certified fasteners have not been in compliance with the product standards and the applicable material certificate. Often occurring at bulk manufacturers which are upgrading bulk products to quality products.
2. Traders or manufacturers of fasteners have issued material certificates not respecting the requirements of the product standards
3. Lack of documented traceability, especially to heat treatment batch and batch size.
4. The manufacturer is modifying the material properties of the starting bar by forging, heat treatment or machining down big bars to small fasteners without performing mechanical testing of the new material properties
5. Many fastener manufacturers are workshops equipped for threading operations. They are lacking competence of materials, but they are responsible for forging and heat treatment. They issue material certificates not knowing the quality of the processes.
6. Manufacturers modifying material properties of bar by forging, heat treatment etc. without performing new mechanical testing.
7. MPS/ITP does not give sufficient information to ensure traceability
8. Material Certificates as missing reference to MPS/ITP

Most of the problem highlighted by the Statoil metallurgists can be linked to the lack of material competence among the producers illustrated by Figure 9. If the industry is going to continue procuring fasteners from a high number of non-specialized manufacturers, the requirements need to be provided in an understandable form to the manufacturers.

The other alternative is the use of few suppliers that are allowed to build enough experience with consistent requirements. Manufacturing of fasteners require high quality control through dedicated manufacturers. Reducing the number of suppliers by use of an Approved Vendors List could mitigate the problem, and let the few suppliers build knowledge of the production, testing and documentation processes.

The creating of the required documentation for the fasteners is also affected by the lack of using a common standard. The project executing departments at both oil service companies and the upstream companies struggle to interpret the test results provided.

4.2 Barriers for Using Common Standards

4.2.1 Lack of an Agreed Upon Common Standard

There is a wide range of standards applicable for fasteners for subsea applications. According to the interviewees, there is definitely not a need for more standards. The main problem of the standards in use is the small amendments in use by the companies, and the small differences in what is considered necessary between the major operators.

A problem for development and implementation of common standards is that this relies on a common agreement on what the standard is, and until this is agreed upon, the standards may not meet requirements of individual companies. [19]. A vast amount of standards, where some of them are contradictory, does not promote the use of common parts.

4.2.2 Why not NORSOK Standards for Fasteners

As the market for subsea fasteners on the NCS is relatively small, there is little interest from suppliers of fasteners to specialize in deliveries of fasteners according to the standard. This means that there is not much rationale to use the NORSOK standards for bolted joints. Fasteners is an international market, and the NCS is not big enough to create a sustainable market for specialized manufacturers of subsea fasteners with NORSOK specifications.

Use of international standards is a priority from both the NORSOK owners and the major oil companies, with NORSOK incorporating only supplemental requirements. Since operational requirements for fasteners on the NCS and other parts of the world is similar, fastener requirements should preferably be specified by international standards.

One of the main arguments for the unwillingness to abandon the NORSOK standard is the slow updating of the ISO standards. Representatives from the upstream companies claim that the bolt manufacturers have had too much influence on the creating of the ISO standard. This has led to a wide use of the term SHOULD, which in terms has given the manufacturers of bolts an opening to cut down on the scope of the testing that is actually performed.

The NORSOK collaboration is currently doing the job as a forum for gathering of the companies operating on the NCS for discussing experience and sharing knowledge.

4.2.3 Gaps between Common Standards in Use

There are gaps between the requirements in API, NORSOK and ISO standards. This has contributed to the oil companies creating their own set of requirements in order to fill these gaps. Existing industry standards do not adequately address bolting/connector performance in subsea marine applications, related to manufacturing, inspection and assembly.

The major differences between the standards are [25]:

- Nut selection to stud (hardness and size)
- PMI requirements (Positive Material Identification)
- Lot traceability for nuts
- Visual inspection
- Non-destructive testing
- Marking for lot traceability

4.2.4 Inconsistency between Standards and Vague Specifications

A problem that becomes visible repeatedly is the inconsistency in the style and contents of the standards. Inconsistency in style and the mix of scope and guidance with technical content is devastating for the simplicity and usability of the standard. Focus needs to be ensuring standard content is presented as clear, auditable statements of observable and/or measureable requirements and acceptance criteria.

The following example illustrate how the ISO 13628 statements incorporate very little observable and measurable requirements:

> *7.1.1 Individual Components and items of equipment shall meet the specified requirements and be verified by FAT and systems integration testing. The subsea production system:*
>
> *- Shall be manufactured and tested in accordance with predefined qualified materials and quality plans.*
>
> *7.2.1.4 A dedicated qualification/test procedure should be developed for components or equipment requiring qualification due to functional requirement, material configuration or design.*

There are numerous examples of these kind of statements in the common standards.

The difference between the words SHALL and SHOULD in the standards makes a significant difference. The definitions used in most standards are as follows [47]:

Shall: Indicates requirements strictly to be followed in order to conform with requirements from which no deviation is permitted.

Should: Indicates that among several possibilities, one is recommended as particularly suitable without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required. Other possibilities may be applied subject to agreement.

The current form of many of the guidelines, including ISO 13628 are made in the form of a guideline rather than a specification. Wide use of the reference SHOULD instead of SHALL give too many variations in the production, leading to a reduced certainty of what physical and chemical attributes the delivered product possess. This form of a guideline rather than a specification becomes clear as the standard use more pages describing common equipment, than stating the requirements for the equipment.

Another repeating problem is the out of scope placement of requirements. Several standards, including Statoil TR2382, reference ISO 13628-7 Design and operation of subsea production systems - Part 7: Completion/workover riser systems as the general specification for LAS for use in subsea applications.

> *"ISO 13628-7:2005 is limited to risers, manufactured from low alloy carbon steels. Risers fabricated from special materials such as titanium, composite materials and flexible pipes are beyond the scope of ISO 13628-7:2005."*

This illustrates how the specifications are linked to documents out of scope for the standards. If this is supposed to be a general requirement for the material specification, it should be placed in part 1, General Requirements and Recommendations

Another industry wide problem is specific technical requirements that are not anchored in operational procedures. Many of the requirements still exist, due to the understanding that "it has always been that way in the industry. "

These requirements may have large impact on the costs of using new technology, even if the risk mitigating effects of the requirements cannot be found to exist. Many of the requirements clarifications are done together with the correct instance at the end customer at late stages of projects. (N.J. Steinsund, e-mail communication, May 20, 2016). By reducing requirement ambiguity at early stages of projects, development of new products would become cheaper.

This can be linked to basic Project Management theory, where the ambiguous requirements can be illustrated as risks. The increased cost of late requirement clarifications is shown in Figure 10, and is often requirements that would have been cheap to fix in early stages of the technology development.

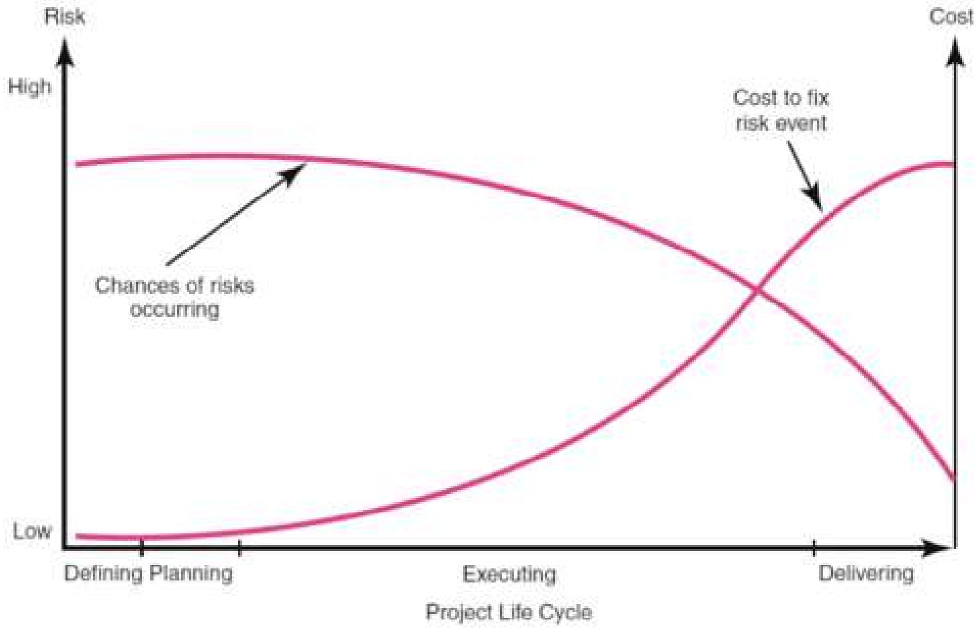

Figure 10 - Risk Event Graph [48]

4.2.5 Lack of Trust

The large amount of documentation required in the industry is a major cost driver. An important discussion is if every part in the supply chain needs to store the information. Even if electronic storage space has become cheap, the large amounts of documents will still be a cost driver. A reason for all instances in the supply chain wanting to have the documentation available is the general mistrust in the industry. The lack of trust between end user, fastener manufacturer and oil service companies contributes to large amount of additional requirements and documentation processes. The recent release of the DNVGL RP for subsea documentation will probably contribute to reducing the documentation cost [49].

Slaattelid [50] finds that Statoil has shifted commercial risk over to the supplier. This should ideally entail a higher risk premium, and may be the reason for the large shift that followed the revision of the Statoil TR3101 in 2012 following the HISC related bolt failures the company had experienced some years earlier. The transferring of risk in the form of requiring traceability has come with a cost.

During my work with this thesis I got a lot of different perspectives from different parties in the industry. The repeating finding is that blame game towards other elements in the supply chain. The oil companies are quick to blame the service companies for the cost escalations, and almost everyone in the supplier industry blames the oil companies.

When calculating life cycle costs, the verification process of the bolt integrity becomes extremely small compared to the costs of failure.

Much of the lack of trust for the integrity of fasteners for subsea applications on the NCS is based on a series of socket head bolts between 2008 and 2011 (discussed in section 4.1.5). Lack of traceability for the bolts also contributed to making the investigation of the root cause of the failures difficult (DNV GL/Aker Solution, Group Interview, 27.05.2016). Investigation after the failures proved that large portions of the bolts had been out of specification, some of the bolts were even far away from the required specification [12].

Bolting technology for subsea applications has been a neglected subject by several major companies in the subsea industry. Many has looked at bolting technology as a simple problem, and has not put effort into requirements for manufacturing methods and qualification of bolts. This has also contributed to the rise of many of the suppliers from emerging markets which have delivered fasteners of varying quality [12].

4.2.6 Conflicting ISO Standards

There have been two initiatives leading to the development of ISO standards for subsea equipment; these are the ISO 10423 specification based on the American Petroleum Institute API 6A specification and the ISO 13628-series based on the NORSOK standards U-001. Currently, there is a conflict of interest between companies contributing to the API-based requirements, and companies supporting the NORSOK based standard. This conflict is based on the giants in the industry positioning for increased influence, and is especially valid for the cooperation between Schlumberger and Cameron, and the merger attempts between Baker Hughes and Halliburton. These combined companies have grown to market power and influence in line with many of the upstream companies, and are now positioning for the reduced market size the oil price collapse has led to. A major part of this positioning is the cooperation with the oil companies in the API organization, in their efforts for creating new standards for reduced costs [51].

The most frequent finding among participants in the IOGP Report 500 regards the most important improvements in use of common standards as:

• More attention to national adoption

• Time needed to revise/issue standards, promotion of standardization

• API ISO need joint working in order to coordinate standards.

4.3 Possible Learnings from other Industries

The two industries that stand out as the one where the subsea industry has most similarities, and thus most possible learnings when it comes to standardization is the aviation and space industries. Both operate under extreme conditions where fastener integrity is a high priority.

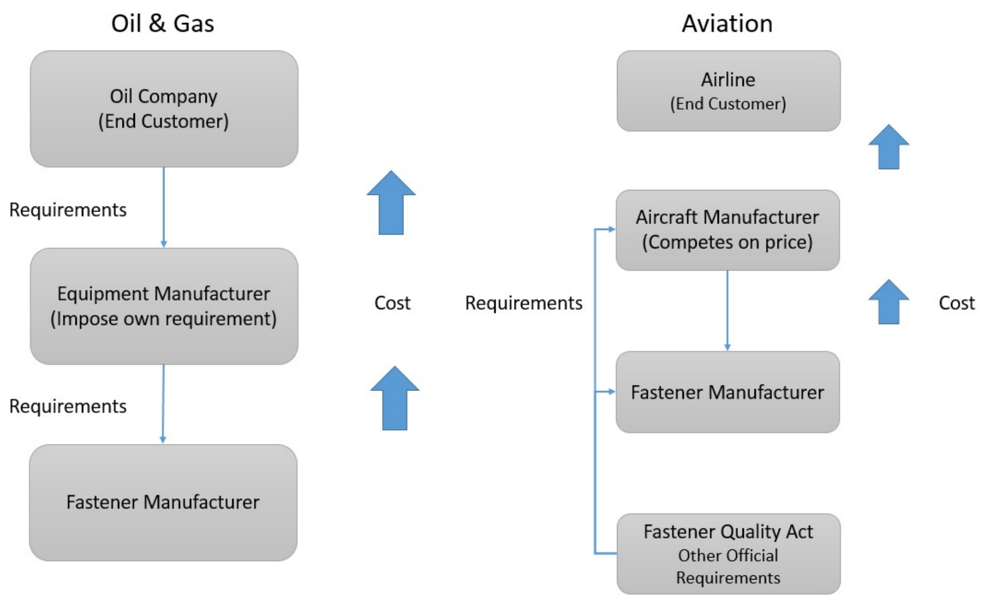

Figure 11 - Comparison of Cost and Requirement Flow, Subsea vs. Aviation

In the subsea industry, the requirements are imposed from end customer and down to the manufacturer of fasteners. The difference between aviation and subsea for how requirements and costs are divided in the supply chain is illustrated in Figure 11, where the requirements arise from the end-customer in O&G, whilst for aviation; the end-customer (airline) does not impose any separate requirements. In many cases, the equipment manufacturer add even more requirements for the fastener. This organization does not give many incentives for the producers to propose improvements to the requirements, since all competitors compete for contracts using the exact same requirements, e.g. TR3101 from Statoil.

In addition, Søgård, et al. [2] claims that the subsea industry can gain a great deal from the experience built up in the Offshore Classification Scheme. They have a long tradition of distributed and globalized supply chains, as well as standardized quality assurance processes. At the same time, the industry have needed to continuously develop innovative solutions in a competitive market [52].

4.3.1 Documentation Requirements

The documentation requirements in O&G have escalated beyond what is reasonable. A JIP has been initiated in order to standardize the required documentation. This resulted in the release of DNVGL-RP-O101 'Technical documentation for subsea projects" released in June 2016 [49]. The results from the JIP shows potential saving of 40% of engineering hours for documentation work.

There have been many initiatives trying to create common specifications for the use of bolted joints. This includes the outcome of a JIP resulting in "Guideline for specification, design and assembly of bolted joints, Report No./DNV Reg. NO.:2008-1656/1201FBR-56 Rev 1, 2012-06-11." Many requirements similar to the recommendations that are the outcome of the JIP, are found in the publicly available NASA standards such as NASA Fastener Procurement, Receiving, Inspection, and Storage Practices for Spaceflight Hardware: NASA-STD-6008.

NASA has really managed to create simple but strict guidelines for the documentation of fasteners, and for traceability throughout the whole supply chain, with publicly open standards and requirements. An excerpt from this guideline is given in Figure 12.

Fastener Type (Male and Female)	Approved Manufacturer Required	COC	MTR	CVT	Complete Traceability	Partial Traceability
Fracture-critical (FC)	X	X	X	X	X	
Inserts and Nuts used with FC Fasteners	X	X	X	X	X	
Low-Risk Fracture (LRF)	X	X	X	X		X(1)
Inserts and Nuts used with LRF Fasteners	X	X	X	X		X(1)
Fail Safe		X	X	X		X(1)
Low Released Mass		X		X		X(1)
Contained		X		X		X(1)
Retention Devices Like Cotter Pins, Hitch Pins, Safety Wires, and Ties		X	X	X		X(1)

Figure 12 - NASA Procurement and Documentation Requirements [53]

Just as for the O&G industry, traceability of parts is a major concern. Without traceability, the location of suspect hardware becomes difficult and may make dispositions very subjective and complex, perhaps even leading to extensive disassembling of structure or other hardware. To maintain such a level of traceability, lot segregation should be implemented [45].

4.3.2 Design Philosophy

Figure 13 illustrates how Airbus has incorporated modular design in their product series. An important focus has been on spare part interchangeability. This lead to shorter lead times and less complexity since modular design and spare part flexibility allows a lower inventory to cover the same number of X-mas Trees and Manifolds, reducing complexity and costs.

This design philosophy can be adopted by the subsea industry for X-mas Trees, Manifolds and other standardized equipment.

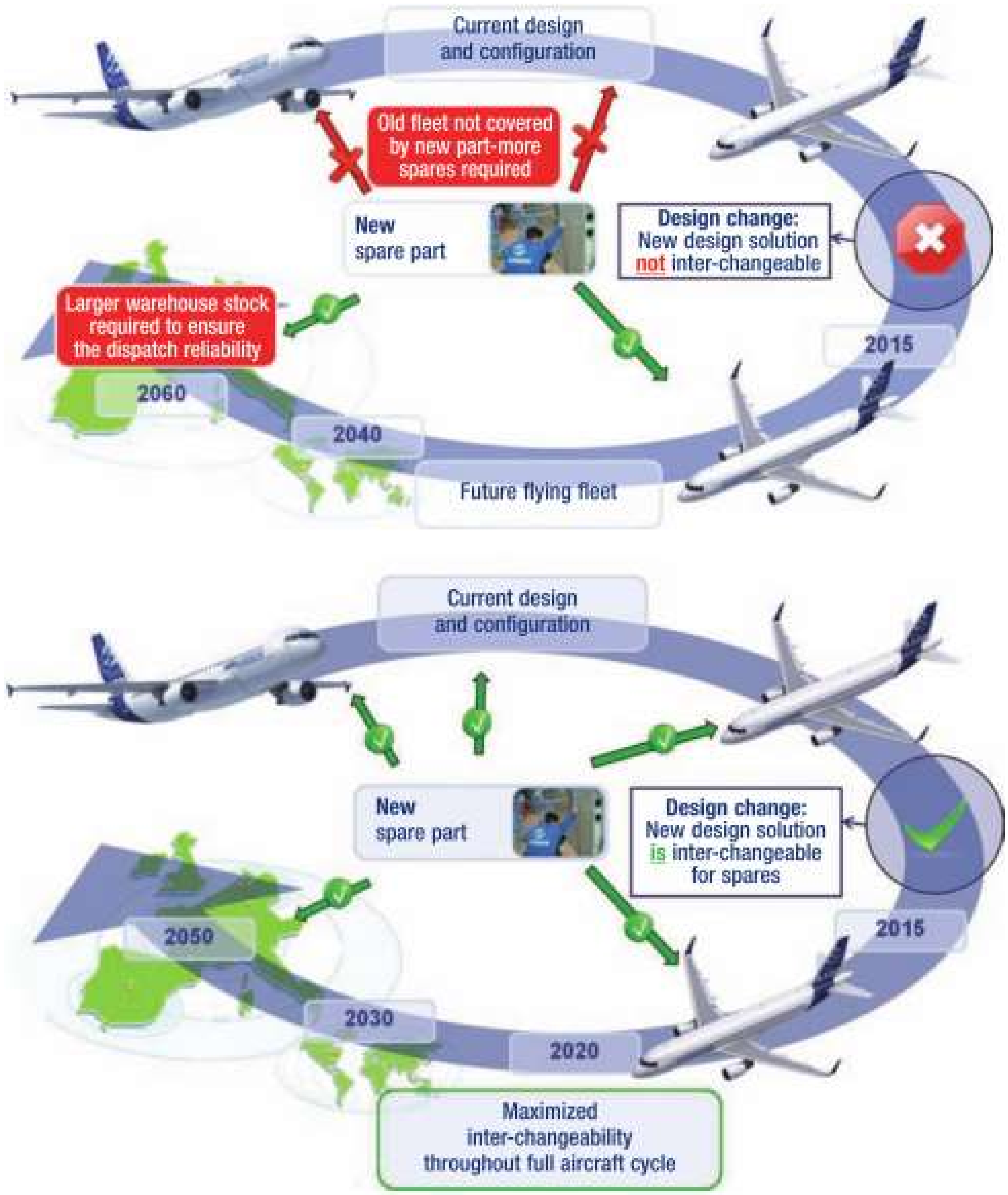

Figure 13 - Modular Spare Part Design [21]

5. Recommendations

5.1 Common Agreement on Which Standard Should be Used

The industry would benefit from a document covering selection of proper fastener material for different environments. This is already an active recommendation from API Subcommittee 21 on Materials.

PSA, in cooperation with the industry needs to agree on what is the recommended specification. Today there are too many opinions and too many specifications in use. It is difficult for the industry to standardize if the major actors do not agree on the basic lines.

A common agreement is crucial for the NCS to maintain its competitive advantage. The most important part of cost improvements is about doing the same thing as before, but more effective. If the industry can agree, this will lead to projects being executed faster and cheaper. Located in a high-cost country, the Norwegian petroleum industry need to be more cost effective than others to be able to attract future investments [54].

5.2 Standardization in Product Lines

In order to benefit from the standardization, the subsea industry needs to move from standardizing in each project, to standardized products lines. This can be compared to aviation, where parts are designed to cover multiple Aircraft series (E.g. A320-class from Airbus) in order to reduce lead times, reduce variance in warehouse storages, while covering multiple equipment families.

The goal must be to create spares that are far more flexible and able to cover multiple applications for multiple customers [21]. Clark [19] claims that there is a significant value to be gained by developing means to measure the impact of standards. Adding compliancy to standards as one of the Key Performance Indicators (KPIs) for the department managers of both the upstream companies and the equipment manufacturers would promote the use of common standards. The cost implications of the decisions made by project managers needs to be highlighted, and measuring of KPIs needs to shift focus from the effects for each department, to a companywide benefit measurement. Each department's compliance to standards would be profitable as the organization shifts towards strategic sourcing. This will help the companies gain from the associated benefits of scale through increased part availability, reduced warehouse costs, and reduce the costs of testing.

5.3 Increase Resources for External Standardization

The IOGP report 500 [31] states that on an overall basis, the major operator companies put nearly four times the resources into management and development of their company specific standards, than they do in external standardization activities. Whether this finding is valid for the operators on the NCS is not known, but the large time gap between the revisions of the NORSOK standards indicate too little resources used for external standardization from the biggest oil companies. In a workshop the hosted by IOGP in 2014, even before the drop in the oil price, the benchmarking committee agreed that a 50/50 split between external and internal standardization work would be beneficial. This means that the efforts towards common standardization would need to be doubled. As the oil price reduction has started to make its mark on the earnings of the companies, the standardization initiatives in the industry has become even stronger.

If the subsea industry increase the use of common standards without additional requirements, the market for fastener manufacturing for subsea applications could become sufficient for suppliers to specialize, thus increasing knowledge and ensure consistent product quality.

5.4 Standardize Approval of Vendors

One of the most important findings from this thesis is that the large amounts of scrutiny that has become standard in the industry has a significant impact on the price development. When a sub-supplier has to go through 150 audits a year, resources are not utilized efficiently towards creating value.

Resources need to be used in order to get a common system for approval of vendors for fastener deliveries for the subsea industry. Such a system can with benefit be based on the API Monogram, but with the additions and supplements that would make it useable on the NCS. The system relies on a common agreement between the major actors for which specification should be used.

6. Conclusion

Continuing low oil prices and increased industry-wide beliefs in cost saving potential of standardization has opened for considerable re-thinking in the subsea industry on the NCS. One of the quickest ways of promoting efficiency is by utilizing the benefits of common parts, instead of continuing the trend of using one-of solutions in the same extent as the industry does today. Fasteners are among the simplest parts to standardize in all systems. However, for the subsea industry there is still a long way to go. The industry has tried to standardize for over 20 years without much success. Nevertheless, the drastic oil price reduction in combination with initiatives from both sides of the Atlantic may be the factor that tips the scale for the cooperation between in the industry this time.

Main Cost Drivers

The main cost drivers arising from use of customer specific requirements in the subsea industry are related to low volume procurement and production. Fasteners are basic components of any systems, and thus ideal for mass production. However, when low volume series with custom specifications are ordered, the cost of production, warehouse costs, logistics and documentation per unit increase significantly.

When supplemental requirements add additional process control steps, the production chain may need to be stopped in order to achieve the desired process parameters. As production volumes rise without changing process steps, CNC-machining of fasteners can be relatively cheap, with good process control if the manufacturer is provided consistent requirements that allow building of knowledge and experience with the manufacturing process.

The single most important cost driver found from the data provided by GE Oil & Gas is the cost of traceability. Changing requirements led to a price increase for one of the fasteners from an average procurement price of 0,91GBP in the period 2006-2010, to an average of 58 GBP in 2011. This drastic price increase coincides with the launch Statoil TR3101 revision 2, September 2010. Since there was practically no traceability for fasteners prior to the introduction of Statoil TR3101, a lot of these cost are regarded as necessary in order to ensure fastener integrity and to avoid large costs of potential failure. However, adding traceability should not lead to an immediate price increase of 6000%. Even though the price has been reduced as the fastener manufacturer has become familiar with the new requirements, the price is still on average over ten times the original price for the three part numbers analyzed. Since the introduction of Statoil TR3101, there have been no known bolt failures for fasteners in operation on the NCS. This indicates that TR3101 have had a positive effect for the integrity of fasteners. However, the associated costs should be a subject of discussion.

In addition, the equipment manufacturers also contribute to the escalating costs. A repeated finding from the interviews and e-mail dialogues is the vast number of different part numbers in use for parts that are practically identical. The engineers are given too many choices during the design phase and in many cases, the choice of fasteners seems to have been given last priority. Just as for the 27 paint specifications for yellow paint from FMC, the number of practically identical fasteners with different part numbers in the subsea industry is overwhelming.

Furthermore, the substantial amount of scrutiny in the industry is found to be a cost driver. When a fastener supplier has gone through 150 audits during one year, for a process that has remained practically constant, major cost implications follow. The industry needs to look at the wider picture in order to reduce costs. This includes designing components with a lower number of different fasteners, utilizing consistent requirements and looking into the procurement strategy in order to keep production of fasteners for subsea application closer to production optimum quantities for the manufacturers. The companies also need to start relying on results from other companies' approval of vendors.

A good illustration for the exaggerated use of standards in the industry is found in IOGP [31] report #500. The 22 participating companies in the survey averaged with 453 standards each. The average number of pages for each standard was 28, which leads to a total of 200,000 pages for just these 22 companies. This is equivalent to eight stacks of documents from floor to roof in a normal office. This is a very large amount of complex and detailed documents, requiring large resources in order to keep current. Equally important, this require a lot of resources from the suppliers if they are to be able to keep track of the differences in the requirements.

To summarize, the most important cost escalating factors are the following:

- Set-up costs for low volume production
- Use of resources for clarification of requirements
- High documentation cost per unit
- Increased warehouse costs
- Cost of maintaining standards
- Costs of increased lead time due to lack of part interchangeability
- Excessive use of audits

Main Barriers for use of Common Standards

The original idea for this thesis was to investigate and estimate the costs of using customer specific standards instead of common standards for fasteners in subsea use. This proved impossible, since there is no common agreement in the industry for what standards and requirement that should be applicable for a "standard" subsea fastener. The NORSOK Standards do not incorporate the requirements necessary to be used as-is for subsea fasteners, nor should they be used since fasteners are common parts in the industry, worldwide, and hence should be covered by international standards. This means that there is not much rationale to use the NORSOK standards for bolted joints. Fasteners is an international market, and the NCS is not big enough to create, nor obtain, a sustainable market for suppliers of fasteners specialized for production to subsea standards.

There is a consensus among the participants in this study that there are more than enough standards available covering subsea fasteners, and thus should there be no reason for further development of new standards. What is needed is a joint clarification in the subsea industry for what should be the preferred standards. This requires a cooperation between the major operators, the equipment manufacturers and the authorities through PSA. In addition, the companies need to agree on how to follow up the standards.

Other factors preventing the use of common standards are the gaps in the requirements between them. Small nuances between standards, and even contradictions in different parts of a standard, makes follow-up of the requirements difficult. Additionally, with requirements that are placed in out-of-scope sections, such as the material specification for LAS in ISO 13628, part 7 Completion/Workover riser systems, the standards become a large net of contradictory requirements. What is needed is a joint industry effort, in the spirit of the Three Musketeers, to identify and fill these gaps in one single agreed upon standard. "One for all, and all for one!"

With the uneven distribution of metallurgists and material competence in the supply chain for subsea fasteners (Figure 9), there is not much room for the suppliers to be heard in the development processes for the common standards. This uneven distribution becomes imminent in the way standards are not adopted to available production methods. The large number of metallurgists employed by the oil companies are quicker to update their company specific standards than the common standards, thus the common standards will always be lagging in the implementation of new knowledge. In order to cope with this, the major oil companies need to assign more of their material expertise resources to joint standardization efforts.

Furthermore, the industry needs to look into how the standards can cover the whole life cycle of fasteners, including material quality, manufacturing and final assembly. While welding has been thoroughly covered by most standards for qualification of personnel, processes and materials, the installation of fasteners has been a neglected subject. Even the best Material Standards available would not mitigate wrong installation.

Summary

The difficulty of identifying the cost of the lack of using common standards shows that standardization is far more complex subject than it seems at the first glance. Standardization is a multidisciplinary subject that requires understanding of both supply chain management, procurement, production processes and material specification. In other words, cooperation between engineers and economists is critical in order to cope with the cost escalations. This thesis will hopefully contribute to partly bridge the gap between economist and engineers in order to harvest the benefits of common standards.

Measuring the effects of standardization is a challenging task. With business sensitive data involved, and a huge number of variables related to purchasing prices from sub-suppliers, to equipment manufacturers and up to the end customers, finding a cost estimate of non-compliance to standards is almost impossible. The benefits of standardization of equipment for the operators include reduced costs without sacrificing quality, innovation or safety. Subsequently it will shorten lead times. For suppliers, it will increase predictability and enable the strategic stocking of long-lead items [19]. Being able to exploit these, require substantial amounts of cooperation, strategic thinking and effort from the entire supply chain.

The vague and sometimes contradictory requirements in many of the standards is a returning problem in the industry. With supplements to technical requirements stating, "the equipment must prove extreme robustness", standardization work clearly has a long way to go before the standards serve the purpose of reducing complexity and uncertainty. In addition, the wide use of the term "should" instead of "shall" in the ISO standards makes a significant difference for the possibility to ensure consistent product quality.

Even though the industry is once again in consensus about the needs for standardization of subsea equipment, it will be interesting to see if the standardization initiatives this time will lead to a culture for continuous learning in the spirit of the popular "LEAN-philosophy". The industry has seen several standardization efforts before, but as soon as the oil price has increased, so has the costs. Just as for other cutting edge industries with large margins, the subsea industry press on without collaboration. However, when times get tough, the incentive to cooperate forces everyone to the table. What may be different this time are the global initiatives for standardization of requirements. API has made progress with their API 20E standard for fasteners, now it is time for the operators on the NCS to join forces in order to gather their needs and experiences to coordinate their standards and start following up.

6.1 Recommendations for Further Research

Research is needed in order to perform a gap analysis between the requirements given by company specific requirements, API 20E, NORSOK, ISO and other standards to clarify what work needs to be done in order to merge existing standards into one useable standard.

The cost-efficiency and safety impacts of adding additional requirements should be researched further to be able to make well-educated implementations when the common specification is not sufficient. In many cases, designing away the problem would probably be more cost effective in the long run.

In addition, more research is needed on creating common qualification processes for suppliers. Today, the lack of cooperation between the companies waste large resources on work to approve vendors that already serve as approved vendors for other companies in the industry.

7. References

[1] Det Norske Veritas, "Report for JIP - Guideline for Specification, Design and Assembly of Offshore Bolted Joints," Det Norske Veritas, Høvik, 2012.

[2] B. Søgård, T. I. Kuhnle, and B. Leinum. (2015, November 2015) Joint Industry Project seeks to advance subsea standardization. *Offshore*. p. 66-69.

[3] S. Bø. (2016, 16.05.2016). *Standardisering haster, mener Statoil-leder*. Available: Standardisering haster, mener Statoil-leder

[4] R. Ramsdal. (2014, 2016.04.15). *Her er Statoils "subsea-dödare"*. Available: http://www.tu.no/artikler/her-er-statoils-subsea-dodare/230198

[5] S. Bjørnstad, "Shipshaped: Kongsberg industry and innovations in deepwater technology, 1975-2007," ed, 2009.

[6] R. A. Sandhaugen and H. J. Lindland, "Development and Standardisation: Challenge or Contradiction?," 1992.

[7] P. A. Nilsen, "Subsea Technology Enabling Cost Effective Developments – Subsea History and Perspective of the Subsea Future," 2015.

[8] Norsk Oljemuseum. (2015, 2016.05.15). *East Frigg*. Available: http://www.norskolje.museum.no/en/east-frigg/

[9] Underwater Technology Foundation. (2014). Available: http://www.utc.no/going-gets-tough-go-subsea/

[10] P. Qvale. (2014, 2016.03.28). *Statoil: Standardisering og forenkling kan senke kostnadene med 30 prosent*. Available: http://www.tu.no/artikler/statoil-standardisering-og-forenkling-kan-senke-kostnadene-med-30-prosent/225637

[11] L. Taraldsen. (2015, 2016.03.09). *Mens oljekostnadene eksploderte hadde FMC 27 forskjellige gulmalinger på lager*. Available: http://www.tu.no/artikler/mens-oljekostnadene-eksploderte-hadde-fmc-27-forskjellige-gulmalinger-pa-lager/276101

[12] G. Rørvik, B. Ø. Haaland, and F. Kirkemo, "Fasteners in Subsea Applications: End User Experiences and Requirements," presented at the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, California, USA, June 8–13, 2014, 2014.

[13] S. Brahimi, "Fundamentals of Hydrogen Embrittlement in Steel Fasteners," ed. Montreál, Canada: IBECA Technologies Corporation, 2014.

[14] J. Bruun-Olsen and O. Inderberg, "Experience And Current Status With The NORSOK Subsea Standards," 1997.

[15] A. R. Johansen, T. Langeland, T. A. Tangen, and T. J. Haugland, "NORSOK Standards -Replacing Company specifications in the North Sea," 1996.

[16] S. Klemp, "Standardisering i Statoil," in *Process Owner – Concept Development & Engineering, Årskonferanse Petroleumsstandardisering*, Stavanger, 2010.
[17] A. Nistov, "Petroleum Standardisation," in *Norsk Olje & Gass, Subsea Operations Annual Conference Day*, Stavanger, 2016.
[18] FMC Technologies. (2015, 2016.07.03). *Subseaindustrien har mer enn 20 forskjellige spesifikasjoner for gulmaling* [Sponsored Material]. Available: www.tu.no/
[19] R. W. Clark, "The Value of Standardization," 2008/12/1/ 2008.
[20] P. Boschee, "Forging of Subsea Equipment: Standardization of Specifications Aims to Improve Delivery Time," 2015/4/1/.
[21] T. Buchholz, A. Mason, and K. Jaschob. (2011) Enhanced spare part engineering support. *FAST, Airbus Technical Magazine*. 30-35. Available: http://www.airbus.com/fileadmin/media_gallery/files/brochures_publications/FAST_magazine/FAST47_9-engineering-support.pdf
[22] R. Boas and E. Crawley, "The Elusive Benefits of Common Parts," *Harvard Business Review,* vol. 89, pp. 34-34, 2011.
[23] B. Lillebø, "Bolting materials subsea," in *Materials in Offshore Constructions*, Esbjerg, 2006.
[24] DNV, "Cathodic Protection Design, DNV-RP-B401," ed. Høvik,, 2010.
[25] F. Kirkemo, "Fasteners: Strength and Quality Requirements," presented at the ASME 2014 Pressure Vessels and Piping Conference, Anaheim, California, USA, July 20–24, 2014, 2014.
[26] K. P. Fischer, "A Review of Offshore Experiences with Bolts and Fasteners," 2003.
[27] Tata Steel. (2016.30.05). *ASTM A193 Grade B7 / ASTM A320 Grade L7*. Available: http://www.tatasteeleurope.com/static_files/Downloads/Services/Service%20Centres/Bolton%20Engineering%20Bar%20Metal%20Centre%20(UK)/Tata%20Steel%20-%20ASTM%20A193%20B7%20-%20A320%20L7%20Datasheet.pdf
[28] T. Havn, "Corrosion in sour environments," ed. Stavanger: University of Stavanger, 2015.
[29] T. S. Aspholm, "Hydrogen Embrittlement of High Strength Carbon Steel," BSc Mechanical Engineering, Faculty of Science and Technology, University of Stavanger, Stavanger, 2016.
[30] OG21, "OG21 TTA4 REPORT: SUBSEA COST REDUCTION," 2015.
[31] IOGP, "Benchmarking on standards and technical specifications, Report 500," IOGP, London 2015.
[32] P. Cleary. (2015, 15.05.2016). *'Spec inflation' driving up costs: complex gear costs blamed*. Available: http://www.theaustralian.com.au/business/mining-energy/spec-

inflation-driving-up-costs-complex-gear-costs-blamed/news-story/91e2b867c5453bb16ec31985f484fea8
[33] S. K. Soy, "The case study as a research method," ed. University of Texas at Austin. Unpublished Paper, 1997.
[34] R. K. Yin, *Case study research : design and methods*, 5th ed. ed. Los Angeles, Calif: SAGE, 2014.
[35] A. Foster and S. Robson, *Qualitative research in action*. London: Edward Arnold, 1989.
[36] R. K. Yin, *Case study research : design and methods*, 4th ed. ed. vol. vol. 5. Thousand Oaks, Calif: Sage, 2009.
[37] A. G. Woodside, *Case study research : theory, methods, practice*. Bingley: Emerald, 2010.
[38] C. K. Streb, "Exploratory Case Studies," in *Encyclopedia of Case Study Research*, A. J. Mills, G. Durepos, and E. Wiebe, Eds., ed: SAGE: Thousand Oakes, 2010, pp. 372-373.
[39] S. Brinkmann, *Qualitative interviewing*. Oxford: Oxford University Press, 2013.
[40] U. Flick, *An introduction to qualitative research*, 4th ed. ed. Los Angeles, Calif: SAGE, 2009.
[41] H. F. Wolcott, "Writing up qualitative research," 3rd ed Los Angeles: Sage, 2009, p. 95.
[42] S. Bø. (2016, 2016.05.16). *Full trøkk på standardisering i petroleumsindustrien*. Available: http://www.standard.no/nyheter/nyhetsarkiv/petroleum/2016/--dette-vil-ta-tid/
[43] S. M. B. Solberg, "Cost-efficient low-volume production through additive manufacturing," Department of Industrial Economics, Risk Mannagement and Planning, University of Stavanger, Stavanger, 2016.
[44] Norsk Olje & Gass. (2014, 2016.04.26). *Norwegian Subsea Standardization*. Available: http://www.ptil.no/getfile.php/PDF/Seminar%202014/Undervassanlegg/4%20NOG%20-%20A%20Report%20on%20Norwegian%20Subsea%20standardization.pdf
[45] NASA. (1999). *FASTENER STANDARDIZATION AND SELECTION CONSIDERATIONS, GUIDELINE NO. GD-ED-2201*. Available: http://oce.jpl.nasa.gov/practices/2201.pdf
[46] DNV GL, "Complexity is the Key Cost Driver," *Perspectives,* vol. 1, pp. 10-13, 2015.
[47] NORSOK, "NORSOK standard M-001, Edition 5," in *Materials Selection*, ed. Oslo: Norwegian Technology Centre, 2014.
[48] University of Alaska Anchorage, *Project Management Fundamentals & Applications of Processes*. Anchorage: McGraw-Hill, 2012.

[49] E. Turander. (2016, 2016.06.13). *Back to basics: New DNV GL guideline trashes unnecessary subsea documentation*. Available: https://www.dnvgl.com/news/back-to-basics-new-dnv-gl-guideline-trashes-unnecessary-subsea-documentation-67264
[50] A. H. Slaattelid, "Relational changes between Statoil and suppliers in the last sesquidecade," MSc, University of Stavanger, Norway, 2015.
[51] H. Ryggvik and O. A. Engen. (2015, 2016.04.19). *Størst er trusselen fra Houston*. Available: http://www.aftenbladet.no/meninger/debatt/Storst-er-trusselen-fra-Houston-3811725.html
[52] E. Turander. (2014, 2016.03.27). *Industry's first certification scheme for subsea equipment and components to drive efficiency*. Available: https://www.dnvgl.com/news/industry-s-first-certification-scheme-for-subsea-equipment-and-components-to-drive-efficiency-8004
[53] NASA, "NASA-STD-6008 NASA FASTENER PROCUREMENT, RECEIVING INSPECTION, AND STORAGE PRACTICES FOR SPACEFLIGHT HARDWARE," ed. Washington, DC: NASA, 2008.
[54] H. Ø. Lewis. (2016, 20160317). *Oljeindustrien har halvert borekostnadene*. Available: http://sysla.no/2016/03/16/oljeenergi/oljeindustrien-har-halvert-borekostnadene_82769/

8. Appendices

8.1 Appendix 1: Interview Guide

What do you see as the most important barriers preventing the use of common standards for fasteners, subsea?
What price driving factors do you believe to arise from the use of company specific standards in the O&G Industry?
How do you believe the use of customer specific requirements have affected the safety/risk?
How would you describe the changes in the applied requirements as the oil price changes?
Are there major differences between the oil companies regarding the use of customer specific requirements?
Did other oil companies introduce equivalent requirements to the TR3101 after the discovery of HISC-related problems subsea (TR3101 from 2011)
Is there any difference with the current standardization initiatives compared to previous initiatives that will contribute to making the changes lasting?

8.2 Appendix 2: Interviewee List

Name	Title	Organization
Vebjørn Andresen	Principal Engineer, Materials	DNV GL
Hans-Christian Ly	Department Manager, Materials Technology and Mechanical Analysis	Aker Solutions
Gustav Heiberg	Business Development Leader, Materials	DNV GL
Grethe Valdø	Senior Engineer, Failure Investigations	DNV GL

E-mail Interview/Dialogue Participants

Name	Title	Organization
Lars Magne Haldorsen	Leading Advisor - Metallic Materials and Welding	Statoil ASA
Nils Joar Steinsund	Engineering Team leader IFOKUS	GE Ifokus
Bjørnar Hanasand	Project Manager, XT Department	GE Oil & Gas
Ole Halvor Olsen	Lead Engineer, ER MPS Sub Systems Engineering	FMC Technologies