



Norwegian University of
Science and Technology

Crane Maintenance in the Era of Industry 4.0

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Submission date: February 2017

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Preface

As a part of the two year master programme at NTNU, students are assigned to writing a master thesis in the last semester of the fifth and final year. The master thesis credits 30 study points, and is the only activity during the semester. The Master project consists of a pre- study report, and a final project report. The work is carried out independently by the student. Deadline for the final delivery is at February 8th 2017.

The Master project is carried out by Kasper Fuglem Røkke, a master student of the two year Subsea Technology programme at the Department of Production and Quality Engineering, NTNU.

The project report is a paper where theory and practical knowledge from the crane industry come together to discuss and identify new concepts that are able to add value. Furthermore, it aims to enlighten industry actors and readers in the possibilities and the future of crane maintenance. Obtaining insight into the crane industry has been extremely valuable for the project. Most of these insights have come from Bård Hopen, academic leader of “Kranpartner”- one of the leading companies in Norway in relation to cranes.

The problem description is formulated by Associate Professor Per Schjøberg and Research Assistant Andreas Marhaug at NTNU. The overall theme of the project is *Crane Maintenance*. More specifically the project is related to the industry 4.0 and state of the art maintenance methods, and how one can use this in relation to cranes and crane maintenance.

Per Schjøberg and Andreas Marhaug has been very helpful under the making of this project, providing me with academic guidance, and assistance in structuring the report. Bård Hopen, Academic leader of Norsk Kranpartner, has also been of great assistance creating a deeper insight in cranes and crane maintenance. I would therefore like to show my appreciation, and send out a big thank you to them!

Abbreviations

KPI	Key Performance Indicator
OEE	Overall Equipment Efficiency
RAMS	Reliability, Availability, Maintainability and Safety
TPM	Total Productive Maintenance
RBM	Risk Based Maintenance
CPS	Cyber Physical Systems
ROV	Remotely Operated Vehicle
RCM	Reliability Centred Maintenance
CM	Condition Monitoring
CPM	Condition and Performance Monitoring
CBM	Condition Based Maintenance
LCC	Life Cycle Cost
IoT	Internet of Things
PDM	Predictive Maintenance
NCS	Norwegian Continental Shelf
FOF	Factory of the Future
JIT	Just in Time
SAP	System, Applications and Products in data processing

Definitions

Industry 4.0 refers to the fourth paradigm shift in production, in which intelligent manufacturing technology is interconnected. The first three were mechanization (steam engine), electrification (conveyor belt), and computerization (programmable logic controller / PLC).

Availability is the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or a given time interval, assuming that required external resources are provided (ISO, 2006)

Condition Monitoring is the acquisition and processing of information and data that indicate the state of a machine (ISO, 2012)

Maintenance concept is defined as the set of various maintenance interventions (corrective, preventive, condition based, etc.) and the general structure in which these interventions are foreseen (Waeyenbergh, 2002)

Reliability is the ability of an item to perform a required function under given conditions for a given time interval (ISO, 2006)

Safety can be defined as a state in which or a place where you are safe and not in danger or at risk (Dictionaires, 2015)

Criticality is the combined measure of the severity of a failure mode and probability of occurrence (ISO, 2014)

System is a set of interrelated elements that achieve a given objective through the performance of a specified function (ISO, 2012)

Equipment is a single component or a group of components

Asset can be defined as a useful or valuable thing or person (Dictionaires, 2015)

Accessibility describes in this case, the level of challenges of reaching/ intervening with an object (system, component etc.)

Crane is a device of lifting and moving heavy weights in suspension (TheFreeDictionary, 2017)

Predictive Maintenance is a right-on-time maintenance strategy. Predictive maintenance may be best described as a process which requires technologies and people skills, while combining and using all available diagnostic and performance data, maintenance histories, operator logs and design data to make timely decisions about maintenance requirements of major/critical equipment (Qiu & Lee, 2002)

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Project Summary

Today's companies are facing a series of challenges, experiencing difficulty in increasingly specialized and competitive markets and demanding restructuring processes. The industry needs countermeasures to prove their place in the market, by utilizing the newest technology and concepts that increases efficiency. The only way to overcome this challenge is to implement and use better methods. In the middle of all this, there is maintenance, which for many is a necessary evil, especially in terms of cutting costs.

This main purpose in this Master project is to identify, assess and apply theory and methods from the manufacturing sector onto crane maintenance and the crane industry in general. Two crane categories in extra focus are process cranes and offshore cranes. This is done to find methods to increase efficiency in the crane industry, especially in relation to maintenance. In addition, the concept industry 4.0 in relation to crane maintenance is central, identifying how this concept can result in added value for crane manufacturers, crane owners, crane users and end product users.

International standards do not require advanced technology in form of predictive maintenance and industry 4.0 equipment, but may become a driver in the future for implementation of new technology. Predictive maintenance and industry 4.0 is identified as a good match in general, and in relation to applications for the crane industry. Identifying industry 4.0 value drivers and levers for the crane industry is key to prove the concepts usefulness and versatility. Several industry 4.0 levers are identified, one of them being the ideal operator analysis, which is a lever that removes waste and increases safety in the organization.

Furthermore, these levers represents the content of a typical industry 4.0 enabled system made for cranes, which can help to predict the future of the crane industry and crane maintenance.

Sammendrag

Moderne bedrifter står ovenfor en rekke utfordringer i dagens markedsbilde. De opplever vanskeligheter med dagens stadig mer spesialiserte og konkurranseorienterte markeder, og utfordrende restrukturingsprosesser. Industrien trenger mottiltak for å bevise deres plass i markedet, ved å benytte seg av ny teknikk og konsepter som øker effektiviteten i organisasjonen. Den eneste måten for å overkomme disse utfordringene er å implementere og bruke bedre metoder. I midten av alt dette, har man vedlikehold som for mange er ett nødvendig onde, særlig med tanke på å redusere kostnader.

Hovedhensikten med denne masteroppgaven er å identifisere, vurdere og anvende teori, teknologi og metoder fra produksjonssektoren for bruk i relasjon til kran- vedlikehold og kranbransjen generelt. Dette er gjort for å finne metoder som øker effektiviteten i kranindustrien, spesielt i relasjon til vedlikehold. Det er viet ekstra oppmerksomhet til de to krantypene "prosesskran" og "offshorekran". Konseptet industri 4.0 i relasjon til vedlikehold er i tillegg sentralt i oppgaven, for å identifisere hvordan dette kan føre til økt verdi i organisasjonen hos kranprodusenter, kraneiere, kranbrukere og sluttbrukere.

Internasjonale standarder setter ikke krav til advansert teknikk og metoder, i form av prediktivt vedlikehold og industri 4.0. Men dette kan endre seg, og vil kanskje bli en driver for fremtidig implementering av ny teknologi. Prediktivt vedlikehold og industri 4.0 er identifisert som en god match generelt, også i forhold til anvendelse i kranindustrien. Identifisering av verdi drivere for industri 4.0 i relasjon til kranindustrien er nøkkelen for å bevise tilpassningsdyktigheten og nytighetsgraden av konseptene. En av disse driverne er den ideelle operatør analysen, som er en utløsende årsak til redusert redusert ressursforbruk økt sikkerhet i organisasjonen.

Videre, så representerer disse driverne det ønskede innholdet i et typisk industri 4.0 system som kan implementeres i kranindustrien. Dette kan gjøre det enklere å se på fremtiden innenfor kranindustrien og kranvedlikehold.

1 Introduction

Today's companies are facing a series of challenges, experiencing difficulty in increasingly specialized markets and demanding restructuring processes. (Huhtala, et al., 2016) This is a result from today's economic situation, and increased requirements to individualization. The industry needs countermeasures to prove their place in the market, by utilizing the newest technology and concepts that increase efficiency. Most businesses want to use less resources, while still maintaining or increasing efficiency and quality. The only way to overcome this challenge is to implement and use better methods. In the middle of all this, there is maintenance, which for many is a necessary evil, especially in terms of cutting costs. (Keizer, et al., 2017)

This is where the crane industry comes into play. Cranes have been an important asset for mankind for thousands of years, and is a central part of the modern civilization as we know it today. (Emerson, 2017) The crane industry is facing the same challenges as discussed above, and even the largest companies are struggling to sell their products in today's markets. New investments are low, and the products that are sold, are often very basic when it comes to extra equipment and technology (depending on the crane type). This is a mind-set that can be described as "short term thinking". It looks great on the next quarter's finance papers, but in a long term it may not be the most profitable nor safe method. (Hopen, 2016)

This Master project focuses on identifying state of the art methods to increase efficiency in the crane industry, especially in relation to maintenance. In addition, the concept industry 4.0 in relation to crane maintenance is central, identifying how this concept can result in added value for crane manufacturers, crane owners, crane users and end product users.

1.1 Purpose, goals and objectives

The main goal and purpose for the project is to identify possible areas found in the concepts industry 4.0 and predictive maintenance, which are applicable in the crane industry, mainly focusing on maintenance. A large part of the theory that exists concerning industry 4.0 is meant for pure manufacturing. In this paper the goal is to apply some of this on cranes. Indirectly this is a way to increase the efficiency in an industry where the markets have become very competitive. (Lobo, 2015) It is important to remember that cost is not just money, but incorporates factors such as safety and quality in products and execution. Being sloppy is something that may prove costly after all. The project has a general approach to the crane industry, but the deeper and longest discussions will propagate around process and offshore cranes in the Norwegian market.

To substantiate the main goal and purpose, themes like predictive maintenance, best industry practices, state of the art, evolution of maintenance in cranes, the next generation crane, industry 4.0 value drivers and modern applications of industry 4.0 in cranes are all important. All these themes will be discussed in relation to cranes and crane maintenance, and will be used to assess and propose possible applications, and discuss why these are clever concepts. Another long-term goal is that the results and knowledge from this paper can be used and appreciated by the industry in the future. To break down the goal and purpose, objectives have been defined:

- Discuss the use of predictive maintenance in crane applications
- Identify the current status in the crane industry in relation to maintenance and efficiency, predictive maintenance and industry 4.0
- Provide a discussion on how introduction of new concepts like industry 4.0 and predictive maintenance will influence the crane industry
- Identify and discuss moments and parts from these new concepts that can result in added value, and explain why
- Discuss the possibility to implement these concepts in today's crane industry, and discuss eventual barriers and challenges tied to this

1.2 Problem description

The problem description is formulated by responsible teacher and supervisor Per Schjøberg and co-supervisor Andreas Marhaug at NTNU. There are nine tasks to be answered, with different weight in workload and complexity. The result is presented in this scientific report.

The following questions are to be answered in the report:

1. Give a short presentation of the crane industry, crane maintenance and its purposes
2. Present the relevant and current standards in relation to maintenance and cranes
3. Present the evolution of maintenance as a schematic overview, point out and explain where crane maintenance is located, what the future looks like, and where in the “ladder” industry 4.0 is located
4. Present predictive maintenance, both in relation to industry 4.0 and cranes. Discuss how cranes may benefit from this. Identify today’s best practices in the industry.
5. Present and discuss industry 4.0, and identify and present modern applications of industry 4.0 in the crane industry
6. Identify industry 4.0 value drivers and levers, and use them in context to cranes in a schematic overview.
7. Discuss the industry 4.0 levers, and how the crane industry and maintenance department will benefit from them
8. Use the information from question 1-7, in particular value drivers to discuss possibilities, barriers and challenges of implementing these concepts.
9. Outline briefly how future cranes and crane maintenance would look in light of this, present the results and conclude the work

(Question 9 is limited in extent, and is provided to make some brief opinions concerning the future of the crane industry. In addition it concludes and contextualizes the work. This is made in consent with supervisor Per Schjøberg.)

1.3 Scope and limitations

The project report is a paper where theory and practical knowledge from the crane industry come together to discuss and identify new concepts that are able to add value. Furthermore, it aims to enlighten industry actors and readers in the possibilities and the future of crane maintenance. Obtaining insight into the crane industry has been extremely valuable for the project. Most of these insights have come from Bård Hopen, academic leader of “Kranpartner”- one of the leading companies in Norway in relation to cranes. The main focus area is concepts for use in cranes and crane industry, with extra attention to process and offshore cranes in the Norwegian market. Other keywords are industry 4.0, the future crane, evolution of maintenance and value drivers.

One of the major challenges throughout the project has been sourcing of crane articles in relation to maintenance. Scientific articles concerning the matter are scarce, and most of the information that can be found, are located at manufacturer websites. Therefore, generic maintenance articles has been sourced, identified and applied on the crane industry, which has been time- consuming.

Many of the aspects discussed are somewhat universal, and are easily applicable for all manufacturing businesses. In fact, most of the information regarding this relatively new concept of industry 4.0 propagates around manufacturing. Because of this, no specific systems and cranes are discussed. Therefore, discussions concerning technical aspects of the systems are limited in extent.

In Addition, predictive maintenance and condition and performance monitoring is a relatively new field, and therefore sources are limited, especially information and concepts developed exclusively for the crane industry. Accessible information about industry 4.0 is also limited, due to the same reasons mentioned above. However, these factors contribute to making the project new and exciting.

1.4 Actors involved in the project

1.4.1 NTNU

NTNU is the second largest university in Norway, and is located in Trondheim. NTNU houses approximately 23000 students, which are spread across 7 faculties and 48 departments. This project will be carried out at the Department of Production and Quality Engineering (IPK). The department is located under the Faculty of Engineering, Science and Technology. The department has four research groups; Production systems, Production Management, Project and Quality Management, and Reliability, Availability, Maintainability and Safety (RAMS). The department has a close relation to the researcher groups at SINTEF, and a wide industrial network that students benefit of in their project work and master thesis.

1.4.2 Actors from the industry

Norsk Kranpartner is an engineering company that aims to solve the industries needs when it comes to material- handling. They are one of the leading companies in Norway, possessing engineering competence in both mechanical and electrical constructions. Whether an object shall be lifted, transported, positioned, operated manually or fully automated, it is not a problem, just an exciting challenge. “Nothing is impossible and should be untested”

With their great knowledge and experience within cranes and crane maintenance, they have been of great assistance in this project, creating the needed understanding of the crane industry.

Other than that, it is the intention to make a project that can be relevant for all industry actors. The topic for this project is very actual and relevant for many companies, and feedback from them has been received, showing their interest. The project is open for everyone to read.

1.5 Structure of the report

To make the report more alive and involving, the structure is set up in a particular way. Throughout the paper, the generic theoretical framework is presented first for the individual matter, then directly followed by more crane specific discussions. This is repeated throughout the project, more or less. This prevents long and tedious periods of theory.

Below a brief description of the chapters and where to find answers on the problems is presented.

The first chapter, introduction deals with presentation of goals and objectives, problem description, scope and limitations as well as description of actors involved in the project.

Chapter two gives an historic background to the crane industry, stating the role of the crane industry in the society. This chapter partially answers question 1 from the problem description.

The third chapter acts as a brief overview of general trends in the industry today, with an extra keen eye on the manufacturing industry. This to give a comparison in relation to the crane industry later.

Chapter four presents some key numbers and trends in the crane industry, and partially answers question 3.

Chapter five gives a thorough walkthrough on the most relevant maintenance concepts and methods that are used in the project, and works as the main theoretical framework for maintenance. The result is a schematic overview over the evolution of maintenance, and a presentation of the purposes of the different methods. The chapter answers question 3, and partially answers question 4.

Chapter 6 presents relevant standards and regulations in the project, and provides a discussion on how they affect the crane industry and crane maintenance. It gives definitive answers on question 2.

The seventh chapter is created to define two important crane categories in this project: process cranes and offshore cranes.

Chapter 8 is named State of the art crane maintenance, and aims to look at current maintenance routines and methods in the industry today, especially in relation to process and

offshore cranes. A chapter that focuses on why process and offshore cranes will benefit from modern maintenance methods, together with a presentation of state of the art crane companies, and their newest technology. At the end, the schematic overview created in chapter 5 is used to pinpoint where in the development- cycle crane maintenance can be found. The chapter gives answers partial answers on questions 1, 4 and 5.

The ninth chapter introduces the concept industry 4.0, which works as an important theoretical framework for the rest of the project, giving answers to question 5.

Chapter ten is all about the merging of predictive maintenance and the concept industry 4.0, discussing some solutions that already exists, and various benefits of merging the two concepts. The task partially answers question 4, and provides the necessary background to go into the next two chapters.

Chapter eleven presents and discusses the eight value drivers of McKinsey that are developed for the manufacturing industry. The value drivers are set in context with the crane industry, leading this chapter further into chapter twelve. This chapter partially answers question 6.

Chapter twelve is the largest and the most important chapter in this project, applying the knowledge from manufacturing on crane maintenance and the crane industry, to identify, assess and present 13 industry 4.0 levers for use in the crane industry. These levers can be used in cooperation with a predictive maintenance system to greatly save costs and add value to the organization. The chapter answers questions 7 and 8, and partially question 6.

Chapter thirteen provides a future framework for the crane industry, discussing what the industry must deal with in the coming years. In addition some thoughts about the next generation cranes are presented in light of the knowledge obtained throughout the project are provided. The chapter partially answers question 9 from the problem description.

The fourteenth chapter provides a brief presentation of results obtained from the project, and concludes the work. In addition, a short note concerning further work is provided. The chapter partially answers question 9.

Further, references are listed, and an appendix including the pre- study report can be found at the end of this paper.

2 History of the crane industry

Cranes have been important for development of society since mankind first started to build advanced towers. Nowadays, the crane industry is a branch in great development and change. Especially in the last 20 years, we have seen an evolution with the entry of mobile, autonomous and all terrain (AT) cranes, creating a very competitive industry where technology and first knowledge are key factors to success. As an example; worldwide construction cranes has sold for 75 billion dollars in 2015 (Lycrane, 2015)

Over the years, cranes have developed and become more sophisticated as the rest of the community. In the modern years, a breakthrough came in about 1990, when there was a transition from old type of motors to the induction motor. (Hopen, 2016) This showed a huge improvement, and dominated the market totally shortly after being introduced. With this great change of motion management on cranes, a whole new world opened for concepts and themes like automation, operation and information flow.

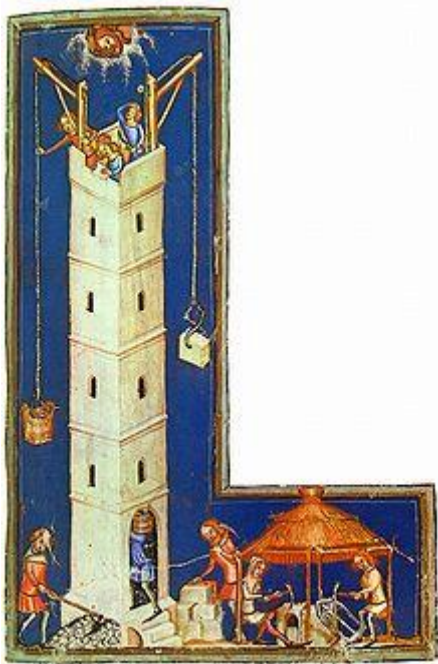


Figure 1 The construction of the tower babel (Weltchronik, 1370)

Lifting equipment has played a major role since mankind invented advanced construction, as illustrated in the picture that originates from the 1300s. In the 1900s, several nations are dominant in the crane industry. The EU has always been in front when it comes to technology, and building quality cranes. This is reflected in the 50% export rate of European

cranes. (Hopen, 2016) Europe is the market where the newest innovations are developed, and is the market leader when it comes to process and offshore cranes.

USA is also a major crane producer, and always has been. It is easy to underestimate their importance, as few American cranes are found in Europe. (Udland, 2015) Their home- market is extremely large, with almost no export. This can be seen in relation to the American car industry. Ford F150 pickup trucks have been amongst the top selling cars in the world for decades. But do we see many of them in Europe? The answer lies in the huge home- market. However, no export may also be seen as a weakness. A huge home market may act as a “sleeping pillow”, and may result in decrease of innovation.

Demag, which is a dominating crane constructor in Europe is today owned by American Terex, so even with no import, we have some American influence. Another big nation when it comes to crane construction is Japan. Much like the American cranes; large home- market and small amount of export, but actually experienced a growth of 22.8 % in 2014. (Technavio, 2015) The European crane industry stands as the dominating and leading innovators and constructors today, at least for industry cranes.

Down below is an estimate of the quantity of each crane category in Norway today. (Hopen, 2016)

- Standard quay cranes 200 units
- Offshore cranes/ pedestal cranes 200 units
- Mobile cranes 500 units
- Tower cranes 1000 units
- Lorry cranes 500 units
- Process cranes 600 units
- Standard industry cranes 10000 units

As we can see, industry cranes greatly outnumber other categories. In this paper, we are going to look at maintenance concepts for cranes, including next generation concepts and technology. Especially, this paper will discuss process cranes, as these cranes have been identified to have a great potential when it comes to installation of new technology. Offshore cranes are also discussed to a certain extent, because of their importance on the Norwegian continental shelf.

3 Trends in the modern industry

Increased competition in the modern markets drives technology further, and as a result, concepts like “industry 4.0” and the “factory of the future” is emerging fast. Companies that want to be market leaders are embracing these technologies, as they both drive and add value to the business organization. Today, these concepts are most widespread within manufacturing. Processes are becoming increasingly advanced, requiring more and more computer force and improved human- machine collaboration.

As stated in the IEC White Paper, that has analyzed today's manufacturing plants and production facilities; *“At present, the majority of manufacturing plants and production facilities around the world are putting into place systems that will make them adaptive, fully connected, analytical and more efficient”* (IEC, 2017)

In this context, the factory of the future represents the new types of factories, utilizing industry 4.0 technology, bringing the fourth industrial revolution to life. Big money is involved as some of the world's largest manufacturer's move towards this, and the global smart factory market is expected to total approximately 67 billion USD in three years from now. (IEC, 2017)

PwC's Strategy& is a global team of strategists, which has analyzed trends in the manufacturing industry. As with IEC, they mention the “Internet of Things”- which is heavily related to the FoF and industry 4.0 together with: (Strategy& pwc, 2016)

- **Robotics**, where the number of shipments of multipurpose industrial robots in China has increased from 75000 to a forecast of 150000 in three years.
- **Augmented reality** is trending, making use of computer vision, computer science, information technology and engineering to deliver real- time information concerning assembly processes, providing guidance, thus decreasing human failures
- **3D printing** have seen an increased usage amongst manufacturers, promoting early testing of ideas in the development phase, increasing time to market and adding value to the organization.

To briefly sum up trends in the modern industry, the industry is in the middle of a technological revolution that is transforming the traditional factories. By embracing these technological advances, they are able to improve productivity and efficiency.

4 Trends in the crane industry

Economically speaking, the industry revenue for manufacturers is following the economic situation in the world. An example of this is the illustrated 25% drop in revenue when the financial crisis hit in 2009. (Figure shows revenue in billions) A mentionable note is that these statistics are for mobile cranes. Statistics for the industry is scarce, held by industry actors, and not publicized. Nevertheless, the general trend is applicable across categories.

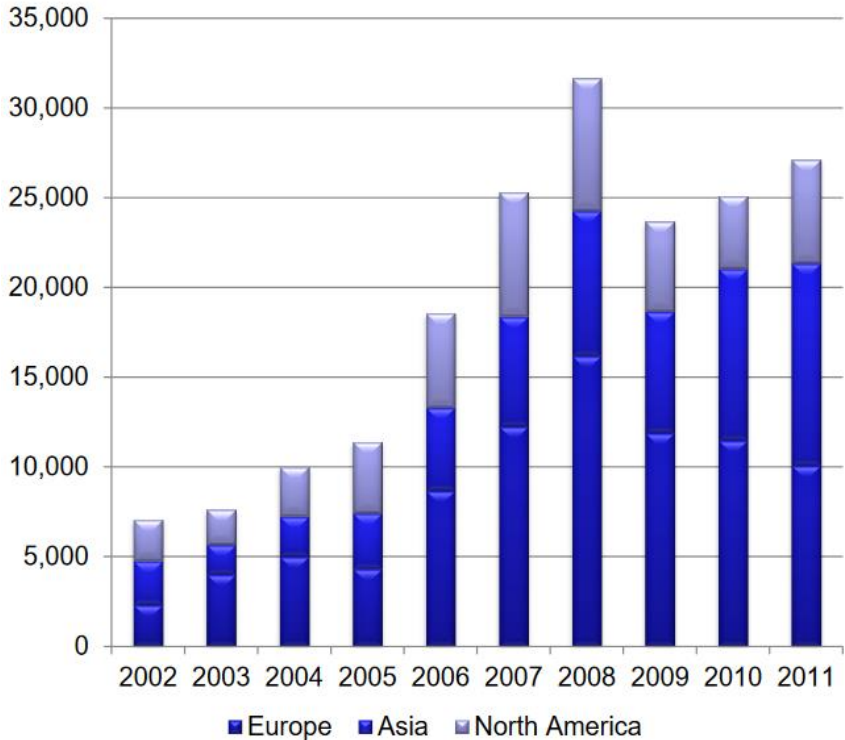


Figure 2 Revenue in the crane industry (Sleight, 2012)

Statistics shows that the top 50 crane owners in the world have a total fleet of approximately 22000 cranes. Even in 2009 the number did not change significantly, as the figure down below shows:

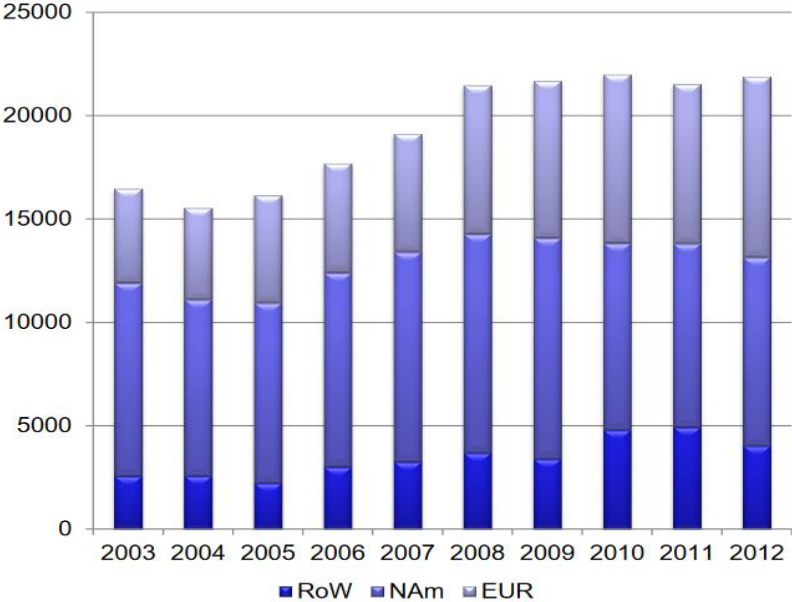


Figure 3 Global crane fleet (Sleight, 2012)

But we also know that the revenue amongst the manufacturers went down in 2009, meaning less new cranes were bought, and less new technology was fitted. It is easy to see that finance plays a big role in the development and evolution of this industry.

As of now, the industry seen as a whole must expect somewhat reduced growth. The Chinese accounts for 30% of the total revenue. Changes in the Chinese economy will therefore create a ripple effect in the industry. The Chinese have had an economic growth of 8-10 % over the last 10 years, but they are not expected to sustain this growth for much longer. (Tong Yi , 2015) This is something the crane and lifting industry must acknowledge and account for.

4.1 Challenges in the crane industry

One factor to overcome this challenge, and secure a steady growth in the industry, is the needs to not only keep up the development of new technology, but to accelerate it. In this way the industry can meet future customer requirements and deliver a quality product. Some of these technologies are identified and mentioned in “*Construction crane industry's future trends and recommendations*”, as:

- lightweight modular designs
- high reliability drive technology
- energy technology
- intelligent manufacturing technology
- networking technology
- product reliability test technology

(Tong Yi , 2015)

For fast progress and development of critical functions tied to cranes fitted with new technology, there should be a great focus on standardization and common functions for these systems, across the branch. This, to increase the safety and keep reputation at a maximum for new technology across the industry. Key areas are reliability, safety, noise, toughness, environmental technology and focusing on improving standard parts, common and materials and shared technology.

Another factor is the need to improve existing business models, or making new ones, improving management quality. In today’s market, having the best product is not necessarily enough. The total package is more, or just as important, as products/ machines are getting increasingly advanced and specialized. Firms that can deliver a good quality product with an equally good service will have huge advantages. Knowledge through the entire organization is therefore hugely important.

4.1.1 Summary of important factors in the modern crane industry

- Big focus on energy saving and regenerating constructions, lightweight constructions and networked technology
- Competitive industry driving each other forwards technology and quality wise
- Last 10 years have generally been good, partly because the growth of the Chinese import market
- Expected decrease growth in the years to come; industry is taking countermeasures (or should), by researching new technology to deliver a better product and service, fulfilling tomorrows demands
- Focus on standardization of common and shared functions in new technology
- Always focusing on safety and reliability improvements, keeping in mind new technology may be flawed safety wise.

An important note is that the statistics used in this chapter is for the construction industry, but it is assumed that the general trends are similar in other sectors.

5 The evolution of maintenance- the way from reactive to self- maintenance

Every system or component has an expiry date; it is just a question of when. If we were able to answer this question correct every time, many of the modern maintenance methods and principles would be excessive. But by utilizing new and advanced methods, looking at trends of emerging faults, assessing condition and performance, we are able to come pretty close to the truth. However, it has not always been this way. Maintenance is a branch in continuously development, keeping up with modern systems advance in technology.

This chapter will work as a part of the theoretical framework in this project, that illustrates the different stages in maintenance, and what kind of advantages and challenges that are tied to each category. A figure has been made to illustrate the different stages, and is also later used to discuss maintenance in relation to cranes, with themes like “state of the art crane maintenance” and “the future of crane maintenance” etc.

Later, these different stages are discussed in relation to each other and new concepts that are introduced in the project. On the next page the figure is illustrated, with a following explanation.

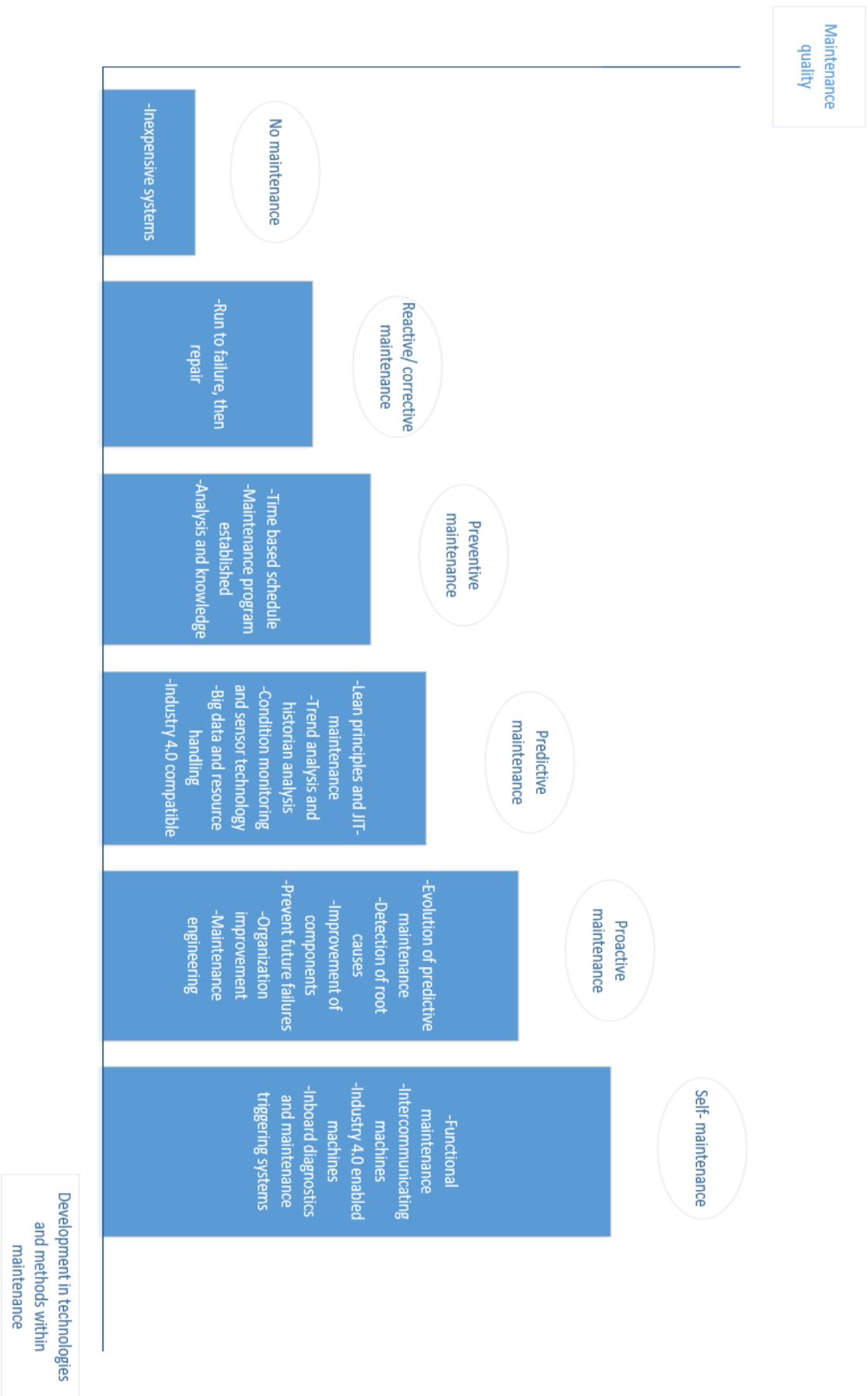


Figure 4 The evolution of maintenance

5.1 Pillars of maintenance

As mentioned, maintenance has developed with technology improvement and the needs of the industry. Modern systems are so advanced that it is imperative that they are kept in shape. Specialized systems need special parts, and an unforeseen failure may compromise the system for an extended time, having economical and safety implications. Therefore, we have methods such as condition monitoring that can track an emerging failure, making actions possible before an eventual failure. In big opposition to the “No Maintenance” philosophy:

5.1.1 No Maintenance

“No maintenance” could hardly be categorized as maintenance, but may be used on systems that are utterly cheap, and not economical to maintain or repair. Some components are only made to last for one use, or until it fails. It is imperative that such components or machines never are used where safety is an issue. Another example of no maintenance philosophy in work is in situations where a way to fix the item is not available, or does not exist. (Qiu & Lee, 2002) This was more common in the early industrial days, or when transportation was more of an issue. Acquiring spare parts to desolate locations was not always easy before. More expensive or available systems have at least been taken care of by the “Reactive Maintenance Philosophy”

5.1.2 Reactive Maintenance

The terms “Corrective Maintenance” and “run to failure” is also precise for this philosophy. The equipment is given very little, or no maintenance until it breaks down. (Qiu & Lee, 2002) When a failure occurs, the machine is repaired with the following stoppages in production and economic implications. In the old industrial days this was in many cases state of the art within maintenance. In that time, maintenance was often seen as a liability, costing money up front, and making unnecessary stoppages in production. HSE was still a foreign word. The systems and machines were much simpler, making them easier to repair, and with a crew of skilled mechanicals and spare parts storage, this method may function. There are also several examples of this philosophy being utilized today, mainly on simple and accessible systems. However, we know today that investing in maintenance is a way to improve the organization and increase the revenue. Utilizing a philosophy like this on a complicated modern system, which may be safety critical, is borderline irresponsible. Wanting more control, and less unforeseen failures, the “preventive maintenance” philosophy was born:

5.1.3 Preventive Maintenance

Predictive maintenance is an evolution of traditional preventive maintenance as we know it. “Preventive maintenance is any planned maintenance performed to counteract potential failures” (DAYA, et al., 2009)

Traditional preventive maintenance is a time- based approach of maintaining. Assumptions and experience about the system/ components will create a basis for the program, and changing components and servicing are done according to age or operating hours. While this may be a good idea in many ways, depending on the system, there are several weaknesses to the approach:

- No early detection of emerging faults, unless you have intensive inspections
- Assumptions and experience may not be correct or adequate
- Components are serviced and changed regardless of condition
- Premature component changes, ultimately leading to losses
- Two identical systems placed in different environment also needs different maintenance, but this may be hard to predict

(Mishra, et al., 2007)

Considered a modern maintenance strategy, Preventive Maintenance replaces components at fixed intervals, either operational time or age. The components are replaced regardless of condition, but the intervals are often set by the manufacturer or expert, to ensure a sensible interval that is both economical and safe. In the modern industry, this strategy is often seen, included in a program that keeps track of different machines in the system, maintenance history and future tasks. However, this strategy also has its weaknesses. Parts and components are not utilized to the fullest, and often changed prematurely, with economic implications. In addition, there is no way to predict an emerging failure, so unforeseen events may lead to a failure and corrective maintenance. An alternative approach to the traditional preventive maintenance is therefore needed. Especially on safety critical systems, systems that are largely inaccessible and systems that is expensive in nature. This leads us to the introduction of “Predictive Maintenance”

5.1.4 Predictive maintenance

Predictive maintenance utilizes the “just- in- time” principle. (DAYA, et al., 2009) It is all about using the individual components to the fullest, using the condition of the component at the time to make judgements concerning maintenance activities. This, of course requires loads of data and information, together with experience and people skills. Some of the tools normally used are:

- Performance and diagnostic data
- Maintenance historian
- Operator data
- Design information

(Park, et al., 2015)

In this way it is possible to closely monitor the process, look for trends and deviations, to correct the process before an eventual error has occurred. The figure down below illustrates the key elements in a predictive maintenance program.

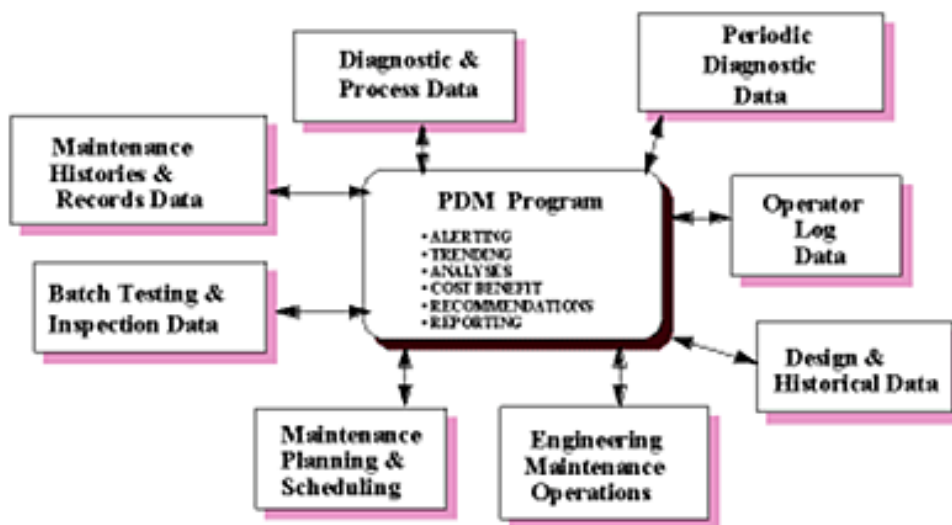


Figure 5 PDM Program (Qiu & Lee, 2002)

A program like this will be more demanding when it comes to resources (data, education, tools), and will certainly be more costly in itself. However, it is a program that will increase the reliability of a system, making decision time gaps larger, improving planning and ultimately reduce operational costs and system downtime. (Park, et al., 2015)

To summarize, the key concepts of a predictive maintenance program are:

- *Combine all information*
- *Analyse information for equipment degradation*
- *Determine corrective action*
- *Prediction algorithms*
- *Determine when to take corrective action*
- *Feedback action taken for maintenance history and/or root cause failure analysis*
- *Be proactive*

(Qiu & Lee, 2002)

5.1.5 Proactive Maintenance

Proactive maintenance is also a sub- art of preventive maintenance, and aims to prevent or/and predict equipment failures, using two slightly different methods/steps: (Qiu & Lee, 2002)

- If a component has failed, there is always a reason for the failure. In proactive maintenance, the reason behind the failures are assessed (root causes), and not only the symptoms. This can be exemplified by using a situation from the auto workshop; it turns out that the valve cover gaskets are leaking oil severely, and every time they are replaced, they will leak again after 2 months. Ok, so the engine carries out its intended function, which is to propel the car, but has excessive oil usage and runs somewhat poorly. Replacing the oil cover gaskets will apparently fix the problem for a short time, but keep doing so is obviously not economical nor good for the engine. Proactive maintenance seeks to find the root causes of the problem, which in this case, after some analyzing, can be found to be a clogged crank case breather valve. This results in buildup of pressure over the heads, ultimately leading to the gasket blow out and oil leakages. It also turns out that the breather valve clogging is a consequence of using oil of wrong quality. After these problems are assessed, the car should be a more reliable performer, using proactive maintenance philosophy. The failure is now prevented from the source after the root cause was found.
- Proactive maintenance seeks to prevent future failures. By feeding the maintenance data back to the product design department, it is possible to improve the product even further, making it more sturdy and reliable. (Lukovic, et al., 2016) Now failure and maintenance are accounted for in the specification and design phase. In relation to the mentioned example, the authorized workshop should now report to the producer. The crank case vent has a weakness for clogging, how could you improve this part or failure? Maybe build a less sensitive valve, specify recommended oil more clearly, fit a sensor that monitors clogging etc. Clearly, communication is a key factor in proactive maintenance. The example illustrates the importance of cooperation between departments in modern industry and proactive maintenance.

5.1.6 Self- Maintenance

Self- maintenance is a system where intelligent machines are enabled to run inboard diagnostics, and keep its intended function for an extended time. It is important to differentiate between functional and physical maintenance, and such machines are in the first category. They are not able to physically repair themselves, but by using their inboard intelligence, they can recover the function by trading off functions and prioritizing. This is what functional maintenance is all about. (Qiu & Lee, 2002) Functional maintenance should be used in addition to physical interventions, although it has clear advantages, exerting less pressure on the maintenance organization, creating a time gap for interventions and such. Machines like these can be regarded as industry 4.0 enabled in many ways.

Another way of seeing self- maintenance is having machines that have the ability to trigger and foresee maintenance task. The machine is still self-monitoring and diagnosing, and uses this information to assess the problems, furthermore triggering service request and ordering spare parts. In this way there is no extra linkage between machine and maintenance crew, making the dispatch and inventory management incredibly simple and economical. Saving time and more seamless interventions benefits both the organization and its customers.

Now, since this is a project concerning cranes, the next chapters focuses on crane maintenance, more particular; state of the art crane maintenance, today's situation in the industry and class leading crane manufacturers. The scope is to see this in relation to the overview presented in this chapter, to obtain a better impression of where we stand. Relevant standards that are related to the crane industry and maintenance are presented first.

6 International Standards relevant to cranes

Standards have proven to be increasingly important in today’s competitive and HSE- focused industry. “A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose” (ISO, 2016)

Certifications within certain standards are always a good selling point, or an absolute requirement for making a successful product these days. Companies want to ensure that systems, components and services are safe, and done according to paragraphs made by industry experts. In many occasions, following standards may reduce costs by removing waste and errors. It is therefore important for this project to establish an overview of the standards concerning the crane industry, which is done in the following chapter.

6.1 Crane specific standards

The scope of this paragraph is to create an overview of the current standards related to crane maintenance. Generally, maintenance standards can be found in the ISO 55000- series (Asset Management), but these are more crane- specific. Some of the standards are illustrated in the figure below:

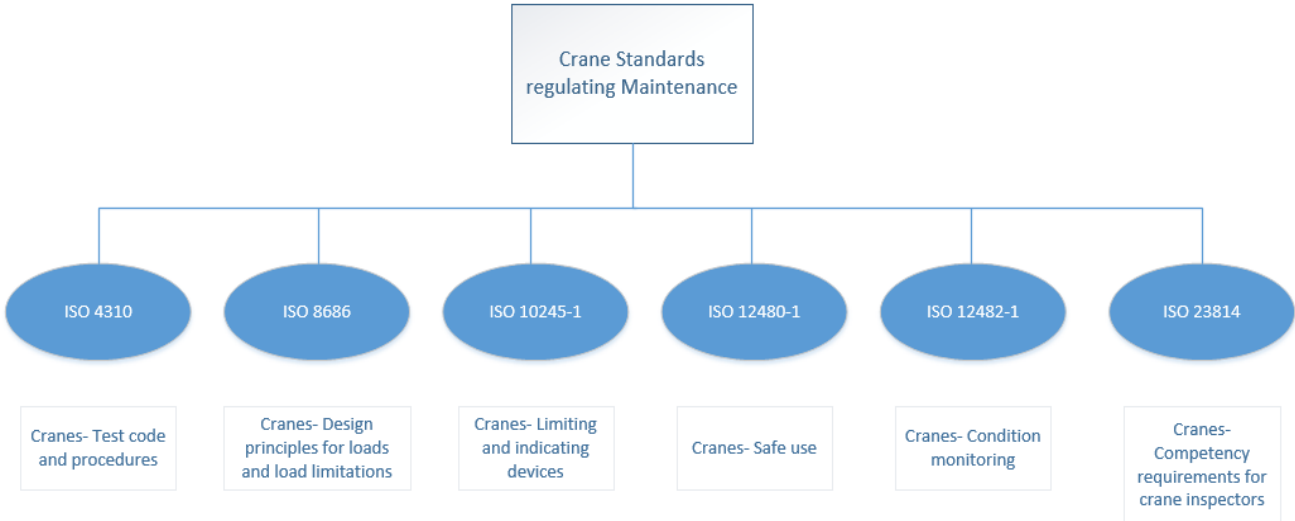


Figure 6 Overview of relevant standards

6.1.1 ISO 4310

This international standard specifies tests, inspections and procedures for verifying the conformance of a crane with its operational specifications and its capability to lift rated loads.

Such tests, inspections and procedures are often carried out after manufacturing prior to first use, after repair or modification/ maintenance, or on a single component of a standalone crane.

Further, the standard mentions different parameters that should be verified in a test or inspection. E.g. (mass, lifting height, cycle time etc.)

The tests and inspections consist of:

- Visual inspections
- Load lifting tests
- Static tests
- Dynamic tests
- Stability tests

(ISO, 2009)

6.1.2 ISO 8686

Named “Design principles for loads and load combinations”, this standard establishes methods for calculating loads and principles to guideline the election of eventual load combinations for proof of competence. It has two different uses:

1. Ranges and content of parameter values, can be used to develop more specific standards, for the individual crane
2. A guiding framework on loads and load combinations between manufacturer, designer and customer, for cranes where specific standards does not exist.

(ISO, 2012)

6.1.3 ISO 10245-1

This standard consists of several parts, named “Limiting and indicating devices” it specifies general requirements for limiting and indicating devices for cranes that are applicable to loads and motions, performance and environment. Devices are defined as operation restricting and/or providers of information to operator or other persons.

It is based upon the principle that the safety of these limiters and indicators depends on regular inspections and maintenance.

Examples of such devices and limiters are:

- Anti- collision device
- Hoisting limiter
- Lowering limiter
- Motion limiter
- Rated capacity indicator

(ISO, 2008)

6.1.4 ISO 12480-1

Named “Cranes- safe use”. As stated in the standard, this part “establishes practices for the safe use of cranes, including safe systems of work, management, planning, selection, erection and dismantling, operation and maintenance of cranes and the selection of drivers, slingers and signalers.”

More specific, the standard states that “to ensure safe and satisfactory operation of crane, a properly planned maintenance system shall be established and used” Furthermore, manufacturer specified intervals should be carried out strictly. Inspections should discover any hazard concerning environment. It also states that an effective maintenance system also will discover the need to prohibit use of the crane until maintenance actions are executed.

(ISO, 1997)

6.1.5 ISO 12482

Named “Monitoring for crane design working period”, and replaces ISO 12482-1 from 1995 (Cranes- Condition Monitoring).

States that cranes are not necessarily designed with a lifetime calculated in time (hours, years etc.), but the number of load cycles and load spectrum the crane experiences. Typically a

crane has an operational period of 10-20 years, but the classification may also be specified for a limited time of use.

Furthermore, monitoring of crane use does not replace other preventive maintenance and inspection, but works as a method to complete the other activities, giving “different information of the condition”.

The design working period (DWP) represents a reliable, but not perfect estimate of the safe operational period of a crane.

The standard specifies a method for monitoring the actual duty of the crane, and also the means to compare the actual duty to the one specified through classification.

(ISO, 2014)

6.1.6 ISO 23814

“Competency requirements for crane inspectors”, as the name may predict, this International Standard specifies the competence needed of those who carry out periodic maintenance, alterations and inspections on cranes. It excludes the actions performed by crane operators and maintenance personnel.

First, the standard includes a paragraph concerning independence, impartiality and integrity. It is important that all inspectors are free from any influence, commercial and economical pressure. This is to ensure that correct and consistent decisions are made after an inspection.

Furthermore, the standard states what types of technical knowledge crane inspectors shall possess and what type of experience is required. The techniques for crane inspections shall be in accordance to ISO 9927 “*Cranes- inspections*”

(ISO, 2009)

6.1.7 ISO 23815-1

Named “Cranes- Maintenance”, this standard establishes the required practices for the maintenance of cranes by users or owners. First, a maintenance program shall be established in accordance with the manufacturer’s instructions. If these are unobtainable, qualified personnel should work out a program.

Minimum requirements for maintenance personnel:

- Competent
- Fully conversant with the machinery they are required to maintain and its hazards
- Properly instructed and trained, including their attendance at appropriate courses where special equipment is used, and
- Familiar with ISO 12480-1:1997, Clause 10.

The standard requires a planned maintenance system, and items that are found to be defective or near defective through inspection based maintenance shall be included in the program. (ISO, 2007)

6.2 Summary of standards

To summarize, the standards specifies and sets requirements to:

- Tests, inspections and procedures
- Load calculations
- Requirements for limiting devices, and basis for the proper operation of these
- Safe use of cranes- what makes it safe to use a crane?
- A requirement of a planned maintenance program
- Requirements and regulations regarding competence of maintenance crew and inspectors
- Requirements regarding inspections, reporting and independencies

From the standards, the requirement of a planned maintenance program is identified. This falls under the category “preventive maintenance” on our overview figure. There is no requirement of condition monitoring equipment on cranes, or other predictive methods. However, being a step ahead is not a bad thing for the future, as we will later see.

6.2.1 Requirements

Back to the crane industry in general, what do the standards require from maintenance?

In the International Standard 12815-1 “Cranes- Maintenance” the following is stated: *“A maintenance program shall be established in accordance with the manufacturer’s instructions. In the absence of manufacturer’s instructions, the maintenance program shall be established by a competent person.”* (ISO, 2007)

Furthermore, the standard suggests that to “*ensure safe and satisfactory operation of the crane, a properly planned maintenance system shall be established and used*” (ISO, 2007)

The bottom line; to be certified ISO 12815, a maintenance program should be in accordance to manufacturer or a competent person, and it should be a planned maintenance system (preventive). In this standard, methods like condition monitoring are not required, but recommended to be implemented in the program for those components in need.

There are, of course a wide variety of cranes, from small land- based utility cranes to offshore cranes that production depends on. Most cranes are a threat to safety if not maintained properly.

Before we now discuss crane maintenance in particular, let’s define two important crane types for this project.

7 Overview of important crane categories

7.1 Process cranes

Process cranes are cranes used in the process industry, often located inside factories. A process crane is a critical asset in the plant, in most cases making a factory inoperable when not available. (Demagcranes, 2017)

Because of this, all cranes are tailored and customized to serve its intended purpose in the best way possible. Typical process industry applications, amongst many are:

- Recycling and bulk handling
- Paper industry
- Process integration - mechanical engineering, automotive industry etc.
- Aviation industry
- Steel handling
- Steel/metal production

(Konecranes, 2017)

The cranes are made, and designed to fulfill specific requirements. Down below picture examples of process cranes from the industry “Demag” are shown:



Figure 7 Demag process crane handling paper rolls (Demagcranes, 2017)



Figure 8 Demag process crane handling of aero parts (Demagcranes, 2017)



Figure 9 Demag process crane parts handling (Demagcranes, 2017)

7.2 Offshore cranes

Offshore cranes may simply refer to a crane placed offshore- on the sea somewhere, used to transfer materials or personnel to or from marine vessels. (Seatrax, 2016) More specifically, we are going to look at cranes fixed on platforms, similar to the cranes we can find on the NCS. These cranes are often called pedestal cranes, as they sit on a pedestal, which is illustrated below

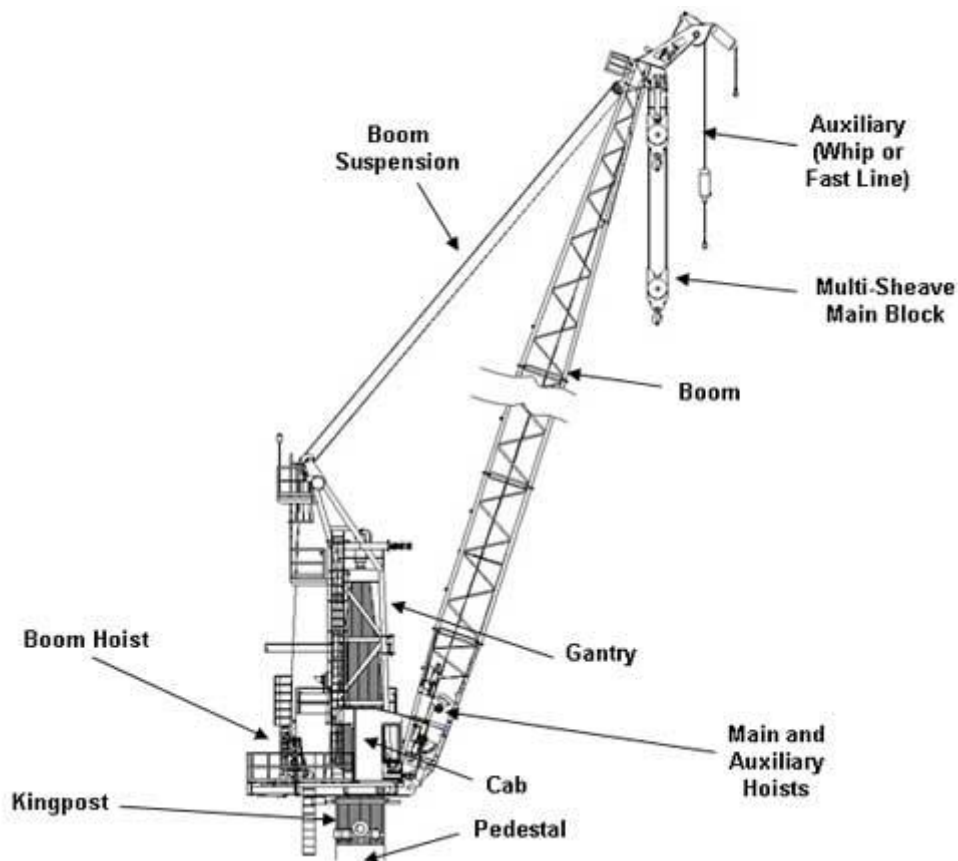


Figure 10 Pedestal/ offshore crane illustrated (Seatrax, 2016)

On the NCS, most cranes turn on a bearing, and not a kingpost, which is mentioned in the picture. The slew bearing with planetary gearing is the preferred solution in Norway. Kingpost has its popularity in USA, and is an arrangement where the crane top is placed on top of a pedestal (kingpost), and rotates on top of it.

There are about 200 of these cranes in Norway, mainly supporting petroleum production on the NCS. (Hopen, 2016) They are therefore very critical when it comes to safety and economic interests. The cranes are often categorized based on criticality, with different demands to availability etc. An unforeseen failure on a critical crane will almost certainly lead to losses in millions of NOK, on top of safety issues. These are fairly complicated and customized cranes, and sourcing spare parts several miles from shore is often a challenge.

This is more thoroughly discussed later in the paper, but this is the reason why it is interesting to look at offshore cranes when it comes to maintenance. The savings that come from improved maintenance performance may lead to huge savings in the long run, if new technology can reduce the amount of unforeseen failures.



Figure 11 Offshore crane on the NCS

8 State of the Art Crane Maintenance

The state of the art term refers to the best practices in the individual industry today, not necessarily the best practices out there. This chapter aims to assess the maintenance- situation in the crane industry today, in light of what is discussed in the previous chapters. Where are we today when it comes to maintenance strategies?

Generally speaking, the industry is still struggling to reduce the number of corrective maintenance actions. Many are not adapting to new strategies fast enough, and when systems are getting old, the failure frequency will increase. This again, will result in a maintenance lag that is hard to catch. The need for maintenance personnel increases, to keep the systems operational, with the corresponding economic consequences. The safety issue is the worst. The industry has experienced several serious incidents (Pallardy, 2016), that is a result of failing equipment, ultimately caused by lack of maintenance and supervision. Therefore, there are both economic and HSE drivers to conquer this problem.

Below is a list of typical maintenance tasks tied to cranes, however, this differs depending on the crane type:

- Inspections of wires and ropes, replacement of these
- Inspections of crane structure, repairs and preventive measures
- Inspections on hydraulic system, diagnostics, replacements and repairs
- Inspections of control mechanisms, safety devices etc.
- Lubrication on key areas, inspections of fluids and refill of these
- Service of engines, generators, gearboxes and replacement of these

(CCOHS, 2013)

These are just examples of typical tasks, not a complete list, which is far more complex.

8.1 Opinions on offshore/ pedestal cranes

In chapter 4.1, some challenges and trends in the crane industry was identified and listed. This included the need to deliver a complete new business model for new customer demands.

Looking deeper into the possibilities of implementing industry 4.0 here will be looked further into.

Also, in 2014, my three colleagues and I wrote a bachelor's degree in engineering, named *"Strategy for maintaining offshore cranes on the Ekofisk field"*

From this degree, we had numerous conversations with service personnel, maintaining offshore cranes as a job. Some of the challenges and problems we found will be included here, and discussed in relation to industry 4.0.

The general opinion after writing the degree was that organization of maintenance jobs was poorly executed. The mechanics had to spend lots of time and effort to get hold of the correct equipment to do the job after they arrived at the platform, making the whole operation more tedious and expensive than needed. In worst case, they had to return before they got the intended job done. In this case the supplier and the operator had a shared responsibility when it came to maintenance, reporting and organizing. (Espset, et al., 2014) Normally, operator crew would take care of the first line maintenance (minor tasks that does not requires special parts or equipment), whilst more advanced interventions was set up according to the maintenance program and coordinated from shore with technicians.

The supplier also felt that the first line maintenance in many cases was defective, or not properly done. This comes down to task like greasing ball joints, inspections after leaks and corrosion, and most importantly reporting. When the service technicians arrived, they would often identify more urgent and critical problems than the scheduled repair. They would then have to postpone the planned task, and take immediate action on the most necessary parts. Furthermore, this resulted in spiraling, and a big lag in maintenance. (Espset, et al., 2014)

8.2 Opinions on process cranes

This chapter is descriptive for Norway's land based process industry. The process cranes are often crucial for the production, being operated 24 hours per day, and have a minimal lifetime of 20-30 years.

Maintenance and operation instructions are based on guidelines from manufacturer. Check lists are made by the industry themselves, based on these instructions and guidelines. Separate lists are made for maintenance personnel and operating personnel. Inspections are done every third week, but intervals may vary up to two months in between inspections.

“The check lists are partly deficient, and crane owner's calls for wear criteria. The check lists are made on a SAP system based on information from manufacturers and experience within the individual companies.”- Bård Hopen

This has resulted in an increase in knowledge about wear criteria amongst inspectors, and how to define wear criteria in the later years. The next step is to improve the detection of wear, and be able to analyze the severity of it, to be able to give a qualified report to the maintenance department, and eventual maintenance actions are made possible.

SAP is the dominating computerized maintenance management system- “CMMS”, in all of Norway's process industry. Although there is no doubt about the resourcefulness of these systems, there are challenges tied to user interfaces and getting useful information out in the daylight. After repeated courses in SAP for cranes in process industry, there are still complaints. At some stages, the program may seem cumbersome, and questions like this have been raised: “How do I feed the program with the information to control the most important parameters, and what are the control criteria?” (Hopen, 2016)

When it comes to condition monitoring equipment, as of today, there are few plans to install such equipment on process cranes. This means that defective check lists and inspections will prevail in the next 20 years. This is definitively a big problem for the process industry, leading us to the next chapter.

8.3 Process cranes will benefit of modern maintenance technology

When we look at the challenges tied to maintenance of process cranes, and their nature, one could say that there is a lack of control when it comes to maintenance. Some of the challenges are:

- Check lists are generic, making them extremely rigid and less adaptable
- Check lists are often deficient, which leads confusion, waste and failures. The equipment is also suffering from this
- The current CMMS's are cumbersome and less intuitive than desirable, leading to further confusion and deficient maintenance
- The supplier often chooses traditional solutions, not installing condition monitoring equipment to prevent being expensive

(Hopen, 2016)

Now, how can modern maintenance concepts and technology help to resolve these challenges, and how do we precede the last two sentences?

8.3.1 Modern maintenance in relation to individualization and tailoring

It is a well-known fact that even similar systems, which are placed in different environments, have the need for tailored maintenance programs. A crane that is placed offshore would have a seriously bigger need of inspections in relation to corrosion, than a similar crane that operates in the land-based sector. In environments, we mean everything from weather, operating schedule, pressures etc. Even a crane that is idle most of its time needs a tailored maintenance schedule, that takes care of patterns and failures tied to idling and standstill. (Espset, et al., 2014)

This is why generic and rigid checklists are not optimal for process- cranes operating at different conditions. These programs will run the risk of not taking care of the individual cranes special needs, which are tied to the condition they operate in, and the use- pattern.

Modern maintenance concepts like predictive and proactive maintenance, which is presented in chapter 5, have the ability to take care of the individual asset in a better way than traditional check- lists. This is done by fitting sensor equipment that closely monitors both performance and condition to make decisions regarding maintenance. In addition, you have the possibility to develop maintenance check lists and inspection routines based on the data that are fed to

you by the monitoring system. This results in a maintenance setup that is highly individualized for the asset, leading to less downtime, increased asset lifetime and less waste.

8.3.2 Modern Maintenance- removing waste and failures

The maintenance crews of the process cranes are struggling with deficient check lists that create confusion, waste and lack of maintenance. Ultimately the cranes suffer with premature wear, sudden failures and decreased lifetime due to this. (Hashemian & Bean, 2011)

In the last chapter we discussed the abilities that are incorporated in predictive maintenance, and that check lists can be made based on the data that is obtained under operation, which will cover most of the needs when it comes to maintaining. Running this philosophy, you have a far better chance to cover everything that is important, and making sure no tasks are overlooked. This will decrease the amount of failures that have risen due to deficient maintenance.

Another advantage is that this minimizes rework, premature component changes by utilizing the just- in time principle. This is a principle that removes waste, and therefore adds value to the organization. (Schmidt & Wang, 2015)

8.3.3 Current challenges in relation to modern maintenance

When implementing new concepts into an organization, it is critical that the systems are thoroughly tested, and that proper training of staff is ensured. If not, the concepts often end up not being used by the staff, because they are cumbersome and confusing, and perform worse than the previous solution. In addition, creating an intuitive system that is easy to use is important. The system may be technically superior, but it does not matter if the staff does not understand it, nor getting any relevant information out of it. This has become a problem in the process industry, where they use SAP- systems to create work orders. It is therefore important to establish testing of the system at an early phase, preferably involving industry actors, and to identify possible areas that are not intuitive enough. In this way it is possible to obtain a system that is ready to use, and a system that no- one is afraid to use.

The current situation in the market is in a way locked, because the suppliers tend to offer the least expensive solutions. This is caused by competition, and a pressure on expenses. Many companies are very well oriented when it comes to up –front expenditures, but sometimes fails to look at long- term costs, and what the equipment does for efficiency. A crane that is fitted with the next generation sensor equipment to enable predictive maintenance is

undoubtedly more expensive than a basic crane. However, if we look at long term expenditures and efficiency of the manufacturing process, the first type of crane may prove to be less expensive for the organization. Some examples of this:

- Longer asset lifetime
- Decreased maintenance costs, increased maintenance performance
- Increased plant efficiency made possible by better asset performance
- Reduced downtime in both asset and plant

Now, how could one convince the suppliers and buyers to choose the more advanced options? The following discussion is provided by Bård Hopen of Kranpartner and the author, as to show some opinions about the matter:

-“The supplier chooses the traditional solution to prevent being expensive. This means that for process- cranes, maintenance- routines will be based on check- lists that are partly deficient, for the next 20 years”

- New technology is often expensive in nature, and the prices are not decreasing unless someone starts investing

-“This is correct, but new technology is seldom used on systems with a low amount of units. For process-cranes, the unit- amount is relatively low, which results in fewer initiatives to develop a complete working system. Process- cranes are in continuous use, and have a large need of maintenance, which makes the gain even bigger when it comes to implementation of new technology. If the investments in this technology are increasing, the expenses also would decrease.

-Standardization is an important moment here, to make the technology more accessible cost-wise. Is it an impossible thought that this type of technology will be available for use in process- cranes?

-“It is only possible if large industry actors start to require this kind of equipment when buying a new crane. In this scenario, the technology would be developed and made easier accessible for other customers in the future. Investing in this type of technology, will result in less expenditure in the future”

-The process cranes, are they not in many ways critical for production and operations?

-“It is the process- cranes that are critical. If they do stop, the whole plant comes to a halt. Many only possess one crane, with no redundancy. In this case uptime and reliability is absolutely crucial. No supplier will actually offer this technology, unless it becomes a requirement from the customers. If this is offered today, the deal is often lost. If new technology is a requirement, then there are no problems. (Hopen, 2016)

So, what results did this discussion bring? The process industry is trapped in a bad circle when it comes to maintenance of cranes. Technology clearly exists, but as long as there are no requirements from buyers, there will be no initiatives. The responsibility is held by the crane owners for the moment, the manufacturers are bound to offer a good price, and are cut off if they offer something extra.

There has to be created an initiative amongst crane buyers/ owners to turn this trend, and to create an initiative the industry should informed about possible benefits and advantages when it comes to use of this equipment.

In the following chapters, the focus will be on identifying possible areas from predictive maintenance and the concept industry 4.0 that are applicable in the crane- industry, in addition what they can do for value, efficiency and reliability in the modern crane- industry.

8.4 State of the art companies

Whiting Cranes, which is an industry leader in the American market is producing overhead cranes for use in the railroad and nuclear power plants. They state that regular inspections and preventive maintenance is the key to extending the life of the cranes, but many companies do not bother to use resources on such programs. They may think it is a waste money and time wise. (WhitingCorp, 2016)

In the bachelor's degree "Strategy for maintaining offshore cranes on the Ekofisk field", we gained insight in the maintenance programs for the cranes on the Ekofisk field. The manufacturer had qualified maintenance personnel to take care of the advanced tasks, but inspections and small intervention tasks were executed by the operator. The program consisted of a mixture of inspections, time- based maintenance and low- tech condition assessments. There was no condition monitoring equipment such as sensors and logging devices installed, but large and expensive components such as the planetary gear had regular inspections with a boroscope, to detect premature wear. Analysis of oil samples on transmissions were also done, which is a type of interval- based condition monitoring. Maintenance lag was a big problem, leading scheduled tasks to be postponed when more serious issues emerged. (Espset, et al., 2014)

8.4.1 Demag Cranes AG

It is time to introduce Demag in this chapter, or Demag Cranes AG, which is a German crane manufacturer, now owned by the American based Terex. Demag has a proud history of manufacturing cranes, dating back to 1906 when they first became the largest manufacturer of cranes in Germany. Their headquarters can be found in Dusseldorf, and they are now an international company employing almost 6000 people. Demag can be described as an industry leader when it comes to cranes, crane components and crane services. (Demagcranes, 2016)

Demag is an industry leader for a reason, and are known to take crane construction and performance to the next level. New technologies in the industry are often seen first on Demag cranes, which make them interesting in relation to this project. First, we want to look at their condition monitoring technology.

8.5 Demag StatusControl

This is the name of Demag's condition monitoring program, which claims to provide the crane owners with real time information through remote access. Benefits tied to this program are reduced downtime, optimized operating processes and better planning of maintenance to reduce costs. Actually, the system is the first to utilize remote wireless access on cranes that delivers analyses and evaluates data in real time. The data is transferred through WLAN or GSM, which is a very common format. (Terex MHPS GmbH, 2016) The idea is that the data feed can be accessed at all times, regardless of location (internet is necessary)

The figure below illustrates three important factors related to maintenance, and how Demag StatusControl influences these factors. The figure is further discussed in the following chapters: 8.5.1, 8.5.2 and 8.5.3

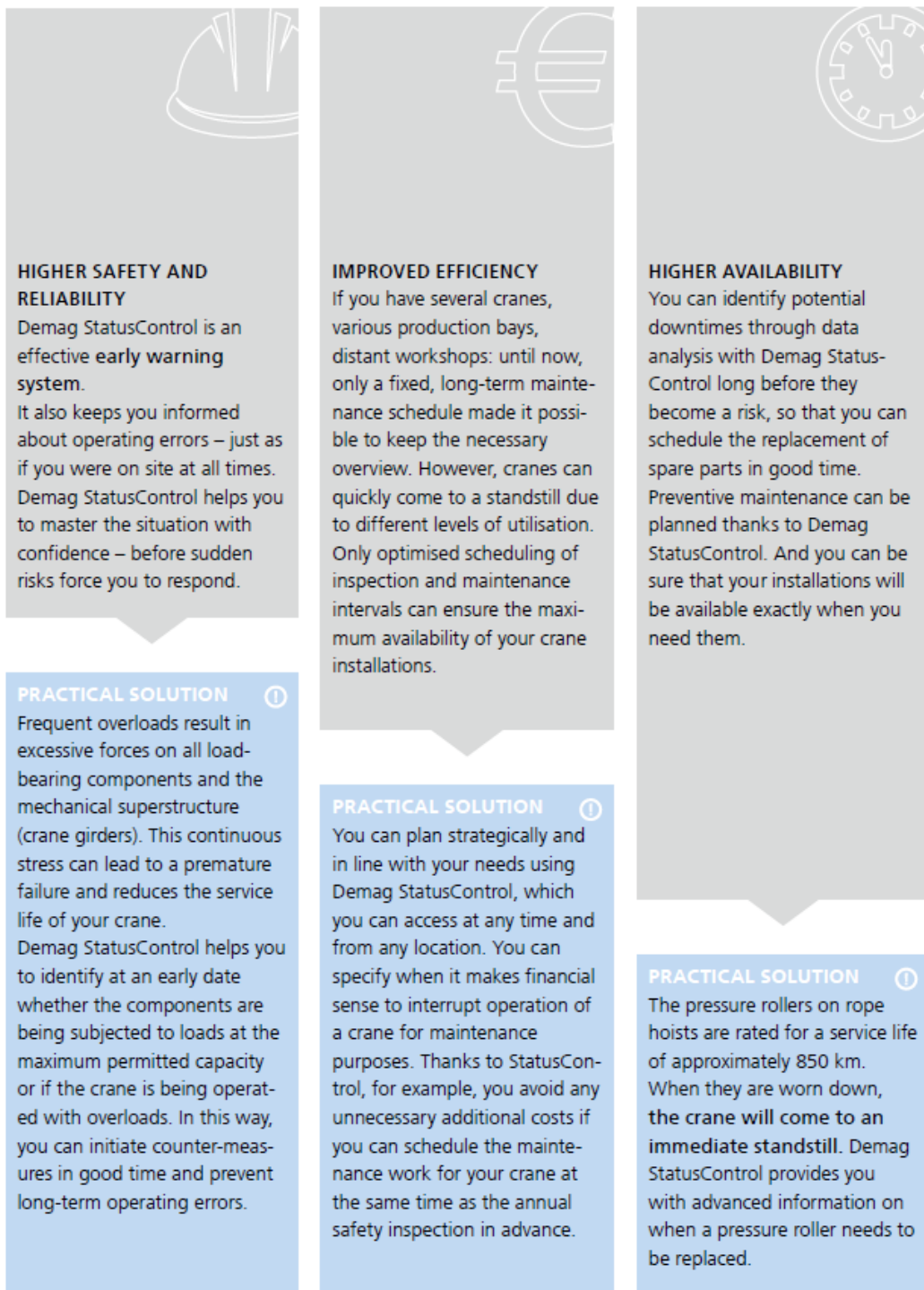


Figure 12 Demag StatusControl solutions (Terex MHPS GmbH, 2016)

8.5.1 Early detection

Early detection is a key factor in modern maintenance. Early detection of an emerging failure can be crucial to safety, costs and plant performance. (Karabay & Uzman, 2008) Planning has always been alfa omega in maintenance, and early detection preferably gives you or your maintenance system enough time to correct the problem in the most sufficient manner.

Depending on the asset/ system, correcting a failure consumes time, time you do not always have when your plant is suffering from downtime. The plant must be shut down/ reorganized, spare parts must be ordered, shipped and handled, maintenance crew and tools must be sourced. Now it is understandable why early detection is such a big game changer. The figure below supports the arguments given, where the effect of early detection can be seen versus equipment, time and cost to repair.

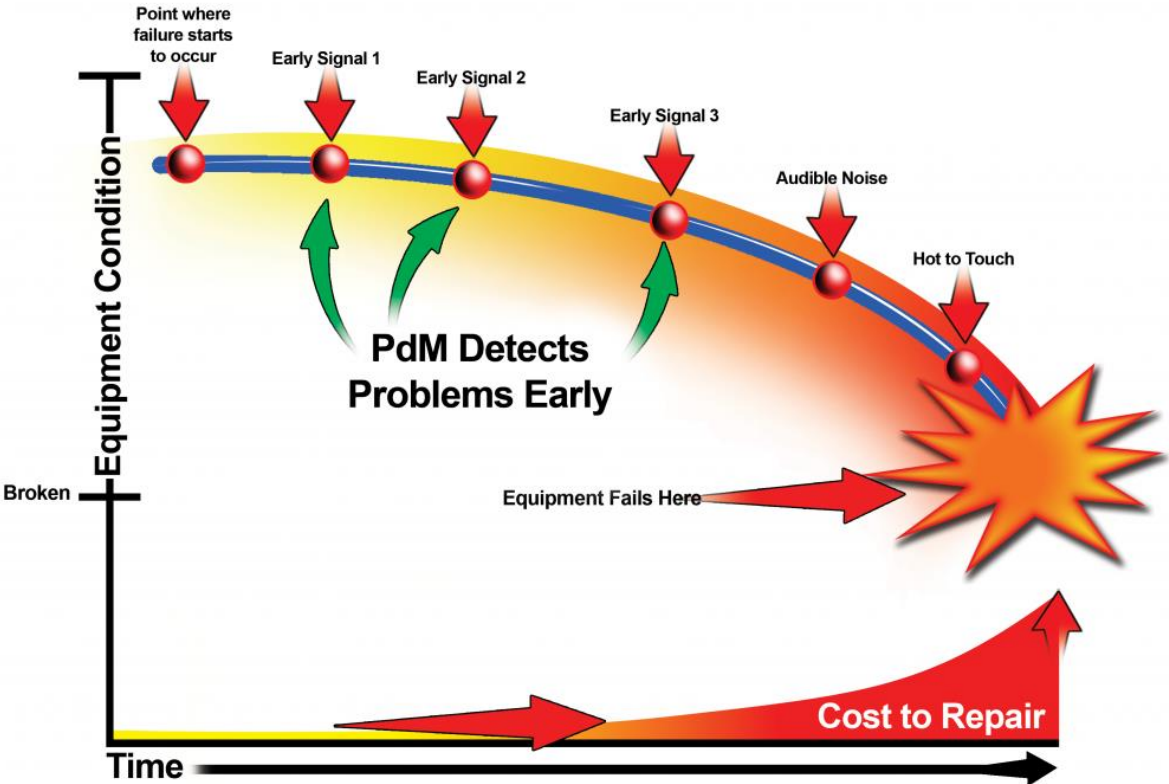


Figure 13 PdM early detection (Sokolowski, 2016)

It is therefore no wonder Demag wanted to make this a priority in their condition monitoring system. An example is illustrated in solutions, concerning overloads on load bearing components, which can lead to premature failure on a crane. StatusControl identifies, and uses a logging tool for such incidents. In this way, the operator receives a warning in good time, to initiate countermeasures and preventing long- term operating errors. (Terex MHPS GmbH, 2016)

8.5.2 Improved efficiency

Improved efficiency is something that every modern maintenance tool or concept should incorporate. A well-known challenge for large companies is to manage different assets at the same time. Large companies often have similar assets, which are placed on different locations and are used for different tasks. A conventional, fixed preventive maintenance program often falls short when it comes to managing several assets like these. Different use and environment must also lead to differences in maintenance needs.

An advantage of StatusControl- system is the way it can manage several assets individually, optimizing scheduling of inspections and maintenance intervals based on use and actual condition. This also prevents losses caused by premature maintenance or component changes, always providing the correct level of maintenance in accordance to the JIT- principle. (DAYA, et al., 2009)

However, the JIT- principle has to be combined with smart scheduling, and StatusControl covers this. As stated *“You can specify when it makes financial sense to interrupt operation of a crane for maintenance purposes”* (Terex MHPS GmbH, 2016)

In many cases, it is not economical to just change one part at a time- you also want to look at adjacent parts that is in for a change at the same time. Sometimes, or rather often, the cost of the operation exceeds the cost of the part itself. This logic is called *“clustering of maintenance activities”*. (Røkke, 2015) This CM- system also makes it possible to schedule such tasks at the same time as revisions, plant stops or at the same time as annual inspections.

8.5.3 Higher availability

This is tied to the early warning system, which will lead to higher availability. Through analysis, potential downtimes can be identified and controlled before they become a threat. A concrete example of this includes the pressure rollers on rope hoist, which have a certain lifetime, putting a crane to a complete standstill if they break. (Espset, et al., 2014) Demag StatusControl provides the information needed to replace the rollers in advance.

It is easy to see that Demag StatusControl has the potential to improve the service quality, safety, reliability, availability and productivity of crane- installations. The system is very adaptable, and fits other products than Demag, which is important for the success of such a service concept.

It is important that the system is designed to be intuitive, and that users are properly instructed and trained. If not, there is a tendency of turning back to the old and safe, which would not promote the “predictive shift”

We have seen examples of this with the SAP- system, where operators are confused what to feed into to program to gain the information needed. The programs need to be developed in cooperation with users, getting hands on experience and giving valuable feedback to improve the product.

At last, Demag StatusControl can be summarized by the figure below:

Full control over your system status information – with features to boost crane performance








-  **REAL-TIME CRANE ANALYSIS**
View current data – anywhere and in real time
-  **WIRELESS REMOTE ACCESS**
Data transmission from the crane via WLAN or GSM – access and evaluate data via the Internet
-  **FOR ALL BRANDS**
Suitable for all cranes and hoists – with contactor or processor controls
-  **CAN BE ADDED TO THE SYSTEM AT ANY TIME**
Flexible integration with existing cranes and hoists
-  **INTERPRET OPERATING DATA**
Easily legible status display on the traffic light principle
-  **INTUITIVE USER INTERFACE**
User-specific information architecture and user-oriented software design
-  **PUSH MESSAGE WHEN STATUS CHANGES**
As soon as a change occurs: receive a call or text message, as required, sent direct to you or a service engineer

Figure 14 Demag StatusControl overview (Terex MHPS GmbH, 2016)

8.6 Summary of modern crane maintenance

With the information above, following preliminary conclusions concerning the maintenance in the crane industry can be made:

- International standards require a minimum, which is a planned maintenance program to be established by competent personnel or manufacturer, but there are no requirements to condition monitoring equipment (predictive maintenance) or higher level.
- The industry are having problem with large amounts of corrective maintenance. This may have several reasons; ineffective maintenance programs and deficient maintenance are some of them.
- In general, preventive time based maintenance is the most common way of maintaining the cranes in a sufficient way today. Those who have a functioning time based program without much lag are doing a good job.
- There are exceptions to anything, there exists more advanced maintenance equipment which is used in the crane industry today, but it is not broadly common.
- Condition monitoring systems and services will play a big role in the future, but it challenges the customers and manufacturers to try something new, and raise their investment costs to lower long term costs.

State of the art maintenance in the crane industry today seems to be mostly professional time-based preventive programs, in addition to inspections and some analysis work. However, there are existing solutions that are developed using industry 4.0 technologies, which we will look further into in the next chapter, coupled with what we know from predictive maintenance. The figure next page illustrates where the crane industry are today, what the standards require, and the future direction in relation to the pillars that were established in chapter 4.

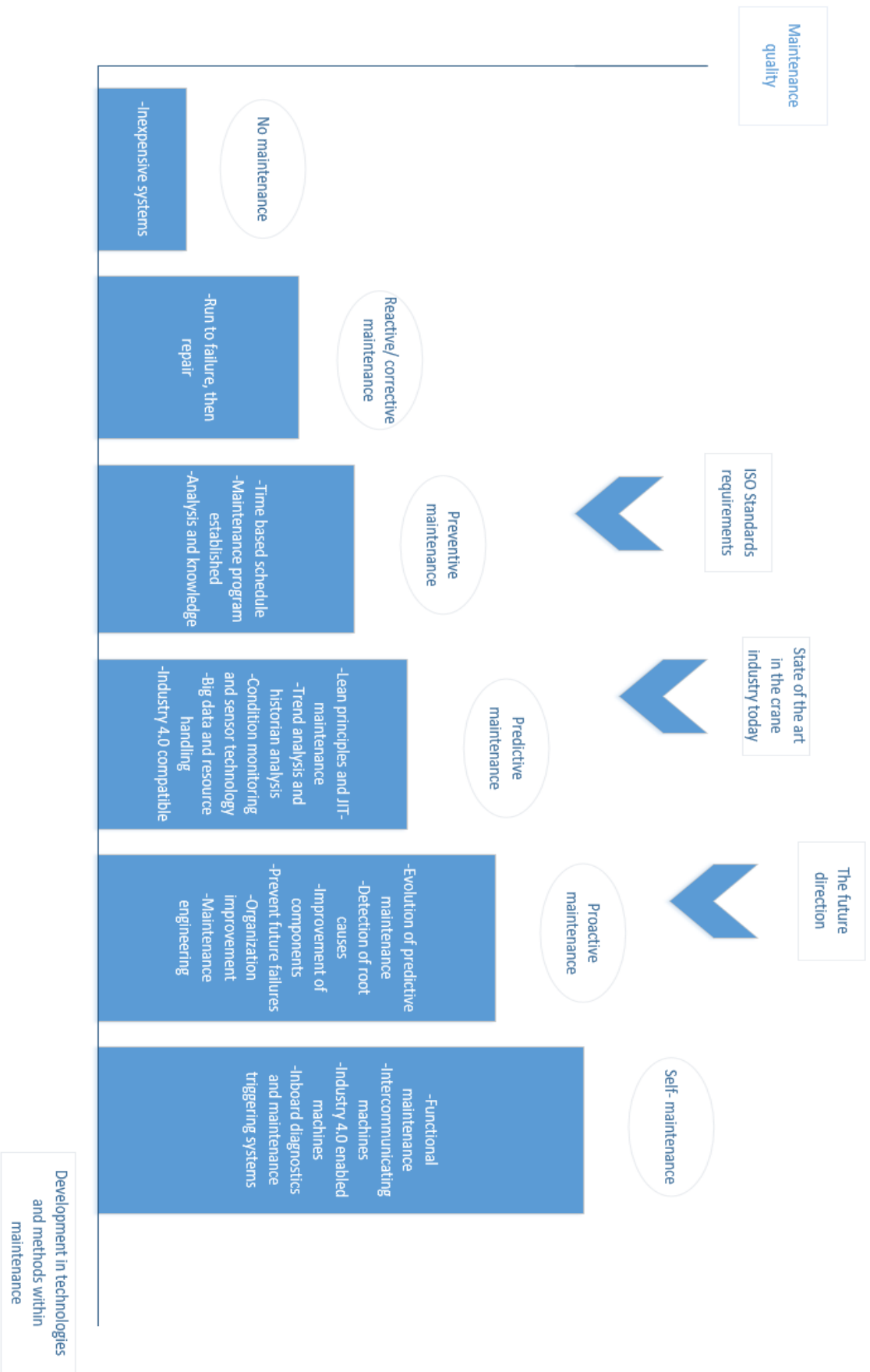


Figure 15 The evolution of maintenance indicators

This means that improvements can be made, which is a good thing. A challenge is to identify how to make the “predictive shift”

What do we need to make advance in technology? Which initiatives shall be taken, and who will make the first step? What will be the main drivers? This will be discussed in following chapters, but the true answer is that no- one should be responsible for the first step alone. This should be a joint effort from the biggest and best players in the industry, making the crane industry more attractive than ever. The concept of industry 4.0 will now be taken into the picture and presented to find out if this concept has relevancy for the crane industry.

9 Introduction to Industry 4.0

The term “Industry 4.0” is relatively new term, and it refers to the initiative of the fourth industrial revolution. Industry 4.0 utilizes the power of cyber physical systems (CPS) and the Internet of things to revolutionize the modern industry. The goal is to integrate the cyber technology in the factories, making the equipment internet enabled. This also enables the equipment to communicate, making the whole factory more coordinated. (EFFRA, 2013) This has many positive synergy effects, like maintenance operation, internet based diagnostics and cost- effectiveness.

Another positive feature of Industry 4.0 is that it creates new possibilities in the market, making new business models for products. It is now much easier to individualize products at a later stage in the process, serving the customer’s needs in a better way than before. A definition of industry 4.0 is stated below:

Industry 4.0 refers to, the fourth paradigm shift in production, in which intelligent manufacturing technology is interconnected. The first three were mechanization (steam engine), electrification (conveyor belt), and computerization (programmable logic controller / PLC). (Lasi & Kemper, 2014)

9.1 Cyber Physical Systems

“Cyber Physical Systems (CPS) are automated systems that enable connection of the operations of the physical reality with computing and communication infrastructures” (Jazdi, 2014) Automated connected systems is something that has existed for a long time, but not so much in the form of CPS. CPS aims to create a network of several devices, and not just for one dedicated device, as most of today’s systems are designed.

Consider devices that we use in everyday life, like cars, phones, coffee machines and garage openers. Not many of these can be controlled remotely, and more importantly, controlled from the same device. Utilizing CPS in such situation would make everyday life more efficient, comfortable and time effective.

Industry 4.0 and CPS has potential in a great range of fields within engineering, including maintenance. Imagine a system that can order spare parts, give information about tools needed, time use, give diagnostics and constant feedback from all different machines/ systems in a plant. All this can be enabled using a system that can handle and coordinate process data.

One benefit, amongst others, is that utilizing this technology for maintenance purposes will give the maintenance crew a superior overview of the plant. It enables you to look at the maintenance from a “plant” point of view, while still having full control of the individual systems and components. This has prior been a challenge, because of the amount of resources needed to actually gather, assess and coordinate the information from the different systems. In this way, maintenance will reap benefits like cost- efficiency on all levels, easier decision-making, and increased quality in execution.

9.2 The evolution of Industry 4.0

Industry 4.0 is a relatively new concept, and was first known to publicity after the Hannover EMO in 2013. (Yen, et al., 2014) The industry of Germany is the main contributor, having over 20 years of experience within CPS. The use of Industry 4.0 has not ended up in concluding results yet, because the concept is in a start-up phase. It is foreseen that several actors from the industry will try to benefit from the use of Industry 4.0 in the near future. Connecting devices, equipping them with sensors, programs and actuators is needed to make this work, and many of the industry actors are likely awaiting for the technology to be properly tested, and the expenses to come down to a lower level. As with everything- someone have to be the first.

More specific, today’s players of industry 4.0 can be divided into three.

- Industry 4.0 technology suppliers
- Infrastructure suppliers
- Industrial users

(Berger, 2014)

Production technologies such as robots and maintenance systems will be provided by technology suppliers like Siemens and Dassault. For data storage, cloud computing and processing, infrastructure providers like SAP will have their contribution. Typical industrial users are global manufacturing firms like BMW and Samsung, which will use the technology to optimize their production processes. The evolution of Industry 4.0 is depending on these players to take part, and develop the concept continuously.

9.3 Industry 4.0 Business model

The introduction of Industry 4.0 has opened possibilities for new business models that can be applied and adapted to customers' continuous change of requirements and expectations. St. Gallen University and BOSCH have already come up with a business model for predictive maintenance, with the use of industry 4.0. By utilizing the strengths of Industry 4.0, it is now possible to have optimized condition monitoring, and a following service agreement.

Components and systems are remotely monitored and assessed, and can automatically trigger service and maintenance work where required. It is also possible to predict an eventual failure, or the risk of a failure, based on deterioration monitoring. In this way, it is possible to always be a step ahead, and use the correct resources at the correct time and place.

The business model itself is named "the magic triangle", and defines the four dimensions of predictive maintenance; who, what, how and revenue. This takes account for both internal and external factors to create a picture of the situation

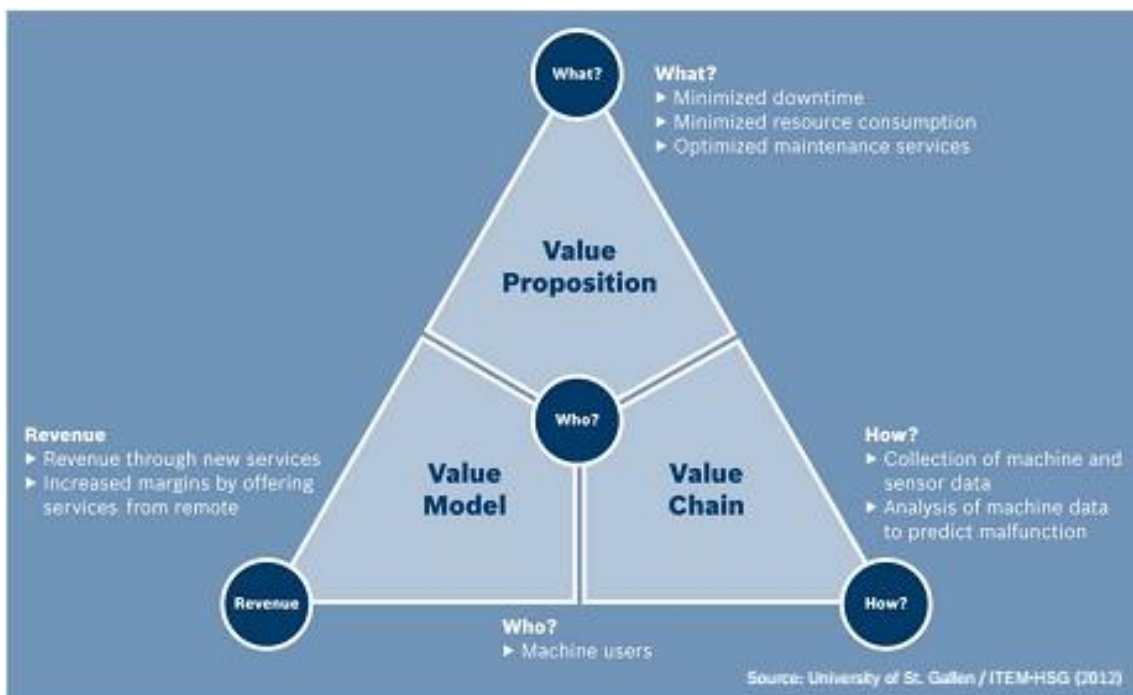


Figure 16 The magic Triangle (BOSCH, 2015)

Who is going to use this type of business model? The answer is mostly industrial manufacturing companies- the users of the machines, systems and components. Therefore the business model should be directed to them, preferably from their suppliers. Services like this are considered to grow in popularity as the complexity of the systems are increasing. We are moving on from the era where it was possible maintain all assets within a company using own

staff. Companies must make a choice between increased education amongst staff, or outsourcing more of the work. Similar tendencies are seen all over the modern consumer market. E.g. new cars are not made for user intervention when it comes to servicing. A plastic shield is all you can see when you open the bonnet, and a fill- hole for washer fluid. The example with autos is exactly the same as in modern maintenance. Increased complexity and warranties makes it harder for non- specialists to intervene. Service agreements like these have come to whether we like it or not.

What is offered to the customer in this case? Early opportunity for planning and determination of when maintenance should be performed, and a complete overview of the condition of the equipment at all times. The customers of the industrial manufactures will now be granted a range of perks, like guaranteed machine availability, while increasing efficiency of the plant. Even better, the end user of the product must appreciate these perks. The quality of the products is increased. Individualization of products is taken to the next level, because customers may now have more choices regarding the products, and the individualization process can be altered in a later point of time. Delivery times should get more on point, with guaranteed machine availability. The perks are plentiful.

How are these tasks resolved? Machine condition is monitored and recorded continuously using sensor technology, and internet availability to report to a maintenance system (CMMS), that can automatically assess data, and control input and output parameters. This is where predictive maintenance modules can be implemented, utilizing condition monitoring technology to assess machine performance and condition. Predictive maintenance paired with industry 4.0 technology may prove to be a successful combination. Predictive maintenance in itself is a great idea, but even greater with industry 4.0 cooperation. Reaction times will decrease, making it possible to correct errors immediately. Communication or intercommunication between machines with predictive maintenance technology is also made possible with industry 4.0 technology

Together, these factors will contribute to **revenue** for the machine manufacturers and industrial manufacturers. Manufacturers utilizing such models have the advantage of a competitive advantage, and better products. Leading the technology forwards, creating additional workplaces and making more money must be the goal for every company. The companies that are the machine users can benefit from an improved organization all over, increasing efficiency, customer satisfaction and revenue. The end user will happily buy and

use products that can improve their lives, that are reliable, and that are efficiently made. By continuous improving, new services can be innovated and create a steady income, and satisfied customers. (BOSCH, 2015)

In the next chapter we are going to look at the concept of industry 4.0 and predictive maintenance together, to identify and analyse if they are a good match, and what types of advantages it is possible to obtain by a merging of the two concepts.

10 Predictive maintenance and industry 4.0

Several industry actors are struggling to make the step from reactive maintenance to predictive maintenance. In fact, the utilization of industry 4.0 in combination with predictive maintenance may prove to be the way forwards. A well know problem for preventive and predictive maintenance programs is the massive data handling required, not to speak of seeing trends in context of the whole system. How can this deviation affect the rest of the system, and may certain symptoms outline an emerging failure in a completely different part of the system?

Handling all this data has proven to be challenging for many companies. This may exert pressure on the organization, needing even more resources to handle information and making decisions based upon the information. (Yang, et al., 2016) This is where industry 4.0 technology shines; Intercommunicating machines, computers that analyze performance readings, using them in the context of a bigger picture. Industry 4.0 makes predictive maintenance data and information more intuitive and easier to handle. Decision making is now not solely dependent on the organization, as the machines often are smart enough to know what is wrong, and when to intervene. This results in:

- Reduced pressure on the organization
- Freeing resources
- Increased efficiency of organization
- Easier decision making
- Increased quality of end product
- Increased availability
- Satisfied customers

(Li & Wang, 2016)

Another positive feature of this concept is that the technology exists, and big actors from the maintenance industry have already developed such predictive programs. One, namely SAP has developed the “SAP Predictive Maintenance and Service solution”, which will be looked further into in the next chapter.

10.1 SAP Predictive Maintenance and Service solution

10.1.1 Objectives

Claiming deeper insight into your assets, this program is aimed for companies that want to move from reactive to predictive maintenance and service. This is done through analyzing mass volume operational data using the “SAP Predictive Maintenance and Service solution” Some objectives of the program are:

- *Enrich asset management to monitor assets anywhere and remotely*
- *Detect system malfunctions using real- time fault management*
- *Improve quality and service by predicting malfunctions before they cause unscheduled downtime and higher costs*
- *Offer performance- based service and dispatch proper technical assistance based on near- real- time monitoring operations*

(SAP SE, 2015)



Figure 17 The Internet of Things

10.2.2 Various benefits for various actors

As mentioned earlier, everyone involved in such a program, will reap various benefits.

Machine owners will minimize their downtime through the use of tools like analysis of operational trends to minimize downtime. This will lead to superior understanding of failure patterns and symptoms, leading to better risk management and better coordination of maintenance operations.

Service providers will have the equivalent to a new toolbox to play with. They can expand their markets, as their offerings get better and broader. Selling total maintenance programs like this, increases the chance to land great deals with large companies. Services are now more agile and quick, including extra services.

For manufacturers like SAP, the possibilities are endless. Innovative new business models can be made, and continuous system improving by identification of issues is made possible. A program like this will grow to be even more efficient and well- made, when going through use. Recalls can be predicted, and warranty costs may be lowered in time. (SAP SE, 2015)

10.2.3 One control center to rule them all

Recent discussions have identified some challenges regarding predictive maintenance. The data handling may prove to be a problem, and keeping a structured overview of the plant is sometimes hopeless. Some of the genius in the SAP program can be found in the control center. SAP Predictive Maintenance and Service provides a single control center for managing assets, historian, trend- analysis, sensor- feed and third- party data. The solution is based on the SAP HANA- platform. (Sikka, et al., 2013) Basically, this platform communicates and connects the physical assets, while keeping a high level of security in the cloud based- interaction system. Cloud based storage, enables the possibility to remotely access data regardless of location and time.

Having all data fed into one control center, that is able to control every asset is a major game changer in relation to more traditional maintenance systems/ programs. The solution is minimalistic and intuitive. Fewer resources are needed to handle the data, reducing the pressure on the organization. It is also believed that fewer errors are made with such a system, because of the superior overview such systems provide. A control center like this could in addition, solve problems like poor maintenance execution or the total lack of it. The threshold

of doing maintenance related activities gets lowered by utilizing such programs, and increases the chance to do them correctly. (SAP SE, 2015)

Now finally, we want to look more specifically into industry 4.0 technology applied on the crane industry and crane maintenance. The following chapter analyses value drivers and levers from this concept that can be applied on cranes.

11 McKinsey eight value drivers

McKinsey digital has developed a tool to identify and prioritize optimization opportunities with the use of eight different value drivers. Adding value to an organization is often all about minimizing or eliminating current losses across the organization. Industry 4.0 is all about information, and the key here is to use the plentiful information to add value. (Tenkorang & Helo, 2016)

As an example, manufacturing companies have machinery and assets as their main cost. (Maintenance, other running costs, depreciation, renewal etc.)

Therefore, machinery and asset efficiency and utilization is a value driver that might have inefficiencies and losses tied to it. Industry 4.0 tools uses information (before unobtainable/difficult to access) to identify losses and utilize the available potential. An example of this is remote monitoring and remote interaction, making use of the information to decrease downtime, leading to added value in the organization. (Weinberger, et al., 2016) Similar examples exist for numerous other organizations, as industry 4.0 has the potential to increase value across an entire product lifecycle.

The McKinsey Digital compass is a new diagnostic framework to identify and prioritize opportunities in the era of industry 4.0. Eight different value drivers are in focus, that are identified as important to typical manufacturing industry. For each of the eight, industry 4.0 factors can help to improve the efficiency. The most important factors are linked to the value drivers, making the diagnostic framework that companies can use to identify industry 4.0 potential in their business. (McKinsey Digital, 2015)

After an explanation of each of the eight value drivers are given, we will use the obtained knowledge to identify areas that can be applied on the crane industry, hopefully to find methods of increasing efficiency. This is also why this chapter exists- to apply predictive maintenance and industry 4.0 methods on the crane industry. The compass itself is illustrated below:



Figure 18 McKinsey Compass (McKinsey Digital, 2015)

As illustrated, the eight value drivers are shown in the inner ring, and the levers/ factors tied to each category are shown in the outer ring. For a given value driver, like service/ aftersales, the levers are predictive maintenance, remote maintenance and virtually guided self-maintenance. These levers are benefits that come from industry 4.0, which can be used to minimize losses across an organization, thus adding value. Similar examples are found for the remaining eight categories of value drivers.

This compass is mainly made for the manufacturing industry. But what about the crane industry? An interesting approach to this is to analyze and identify possible areas found in this compass that can be used in crane applications and maintenance. First, the different categories in the compass are explained, and then there is a following chapter that discusses these in relation to cranes, trying to find new industry 4.0 levers that can drive value further, based on the existing levers made for pure manufacturing. The identification and discussion of levers for cranes is pretty unique to this project, and a lot of effort is made to accomplish this. The figure above is later linked to figure 24 in chapter 12.9, which discusses results.

11.1 Resource/ process

Material usage, process speed or yield is factors that drive value. The first one tied to material cost and the others by increasing efficiency by increasing the output. It is shown that optimization programs for process variables can increase the throughput up to 5%

11.2 Asset utilization

Using the company assets to their fullest is an important value driver in the industry. Companies that are heavy users of assets and expensive machinery are the players that can greatly benefit from improved asset utilization. Production companies that have a large machine park, or transport firms running a great lorry- fleet are examples of such. Not utilizing an asset to its fullest is transferrable to lost revenue for such companies. An industry 4.0 lever like predictive maintenance can improve this greatly. Predictive maintenance is thoroughly explained earlier, but basically, sensor technology and data feed can give information concerning condition, giving early detection so that maintenance resources can be optimized and properly planned, thus increasing availability of a machine. A lever like predictive maintenance can decrease machine downtime up to 50 %, and increase the longevity of a machine by 20-40 %. (McKinsey Digital, 2015)

11.3 Labor

Labor has always been an important cost driver, because improving productivity of the workers does add value. (Hartmann, et al., 2015) The levers in this case would be measures that reduces idling time (delaying, waiting on work orders, waiting for the previous job to be finished etc.), or increasing the speed of the workers by giving them motivation, less strain and more streamlined work- tasks. An effective way to improve working speed is to partly robotize heavy manual tasks, so that workers experience less strain. A furniture company managed to increase sales by 40% by utilizing robotics on previous heavy manual lifting tasks. (McKinsey Digital, 2015) They used robots that collaborated with the workers without compromising the safety. Revolutionizing the labor aspect can add value in different ways as we can see.

11.4 Inventories

In most modern businesses, both warehouse and inventory sizes are well discussed and optimized. In today's world, transport has become more available and cheaper, causing companies to shrink their own inventories and warehouses. The convenience of having a large

inventory is inferior compared to the capital that is being tied up, wastage, maintenance of inventories etc. Finances especially promote this philosophy. (Stadtler, 2014)

However, modern ordering and transport is not perfect, and a way to drive the value further is to reduce excessive supply of inventory further. It is possible to use industry 4.0 levers to improve drivers of excessive inventory. Examples of these:

- Faulty stock numbers, wrong count etc.
- Inadequate planning and knowledge, causing unnecessary safety stock and overproduction
- Furthermore; aging of expensive stock, ultimately causing losses

A ready developed concept to improve warehouse utilization and inventory is Würth iBins. An iBin is a container equipped with optics that records quantity, number and ordering information for the item stored in the container. The iBin has real-time updates, and transmits the information to a computer- ordering system, for example a CPM systems. This ensures just-in- time delivery of small parts needed for production on a requirement- driven basis. (Würth Industrie, 2016)



Figure 19 Illustration of iBin container with optics (Würth Industrie, 2016)

It is said that through industry 4.0 levers like Würth's iBin, it is possible to reduce inventory holding costs by 20 to 50 percent. (McKinsey Digital, 2015)

11.5 Quality

Quality is a part of the six big losses tied to production, established by Nakajima in 1971, and further a crucial ingredient in OEE- Overall Equipment Efficiency. (Vorne Industries Inc., 2016) Within production, there are mainly two aspects of the quality measure; production rejects and startup rejects. Production rejects refers to defective parts produced under stable production, and startup rejects refers to defective parts produced in the startup- period of the plant/machine.

Improving quality drives value because it saves costs compared to producing scrap and products requiring rework. (machine time, labor and materials)

Normally, quality problems come from poor machine performance, unstable processes, faulty machine settings, capacity overload, deficient packaging in the supply chain or poor installation of components/machines. Issues like these can be eliminated by industry 4.0 levers like digital performance management, advanced process control (APC) and statistical process control (SPC), even to add further value, like the car manufacturer Toyota. They use an advanced analysis system to monitor their production lines in real time, to continuously handle problems in the production processes. Calculations suggest that industry 4.0 quality levers could decrease costs affiliated to quality by 10 to 20 percent. (McKinsey Digital, 2015)

11.6 Supply/demand match

For production businesses, matching the supply and demand is a major value driver. This has always been a major challenge and expense, but using industry 4.0 levers can increase the accuracy of supply/demand by 85 percent and more. Maximizing the value- potential tied to supply/demand, means a 100% demand match, which is unrealistic still today.

Using tools like analysis- systems on online web shops, to create statistics and overviews of what customers are looking at, is something that can increase the supply/demand match. (Tao, et al., 2014) Tie this back to a production system that is industry 4.0 enabled, will add another function to the system, increasing the versatility and drives value further. (McKinsey Digital, 2015) Another advantage of such analysis tools is the increased focus obtained, making it possible to target products that are successful/ desirable, and limiting other products less desirable. This will result in a more streamlined experience for customers, decreased development times and production costs.

11.7 Time to market

Launching a new product before the competition is a key factor to success within modern businesses. (Chen, 2015) It creates value-adding advantages like increased revenues, branding, first hand on technology and more. A key factor is to look for demands in the markets that are not already covered.

The automotive maker Tesla is a great example of a successful business who utilized the “time to market principle”. With their long range, high performance, luxury electric cars, they launched a product that caught the rest of the industry unaware. Although questions about the small automobile maker were storming the first years, they are now on their way to prove their position as the leading electric carmaker in the world. Reports also suggest they are finally making a positive cash flow as of October 2016. (Jones, 2016)

Being the first successful maker of high- end electric cars, they now have several advantages like an already developed rapid- charging network, ready to be expanded even more, excelling the competition by far at the moment. They also have invested hugely in a new battery factory, and have already gained years of invaluable experience building electric cars. Their Tesla brand is now synonymous to high- end electric cars, making it a big challenge for established companies like BMW and Mercedes to reclaim lost ground. It is also worth mentioning their use of industry 4.0 technologies in their cars, utilizing integrated internet services, self- diagnostics and self- driving (autonomous) technologies.

The Tesla example underlines the importance of the “time to market” factor. Now, how can industry 4.0 levers create additional value in this sector? We have examples on the usage of 3D printing amongst production companies today, using designs that are sourced directly from forums and internet communities. (McKinsey Digital, 2015) This makes it possible to test prototype designs, and reduce development time by a faster and less cumbersome testing- phase. There are examples of companies that have managed to reduce the development cycle of a product from 7 years to 1 year, being an extreme example. Such scenarios are synonymous to great costs savings. A more typical estimate is that industry 4.0 levers can reduce the time to market by 30- 50 percent. (McKinsey Digital, 2015)

11.8 Service/ aftersales

The advantages of service/ aftersales are thoroughly discussed in the predictive maintenance part. Basically, the operational costs are influenced by service costs. Solutions for reducing service costs add further value, using such systems as SAP Predictive maintenance and Services and Demag StatusControl. These systems utilize industry 4.0 technology and connected devices to run self- diagnostics, and off- site monitoring, improving maintenance performance, quality and efficiency. Typically, maintenance costs are reduced by 10 to 40% by using predictive maintenance systems. (McKinsey Digital, 2015)

As we have seen in this chapter, the eight value drivers may prove to be very important for maximizing the revenue, and minimizing costs for companies that are technology oriented, and want an edge on the competition in the years to follow. From the examples we have seen that several businesses are already utilizing some of the value drivers to be more efficient. However, in this project we want to look mainly at crane maintenance, and efficient ways to improve the crane industry, making it more profitable, increasing quality and lifetime of the products.

So what can we learn from the eight value drivers in relation to cranes? In the following chapter, we are going to look at industry 4.0 levers for crane applications, still based on the eight value drivers we have seen here.

12 Industry 4.0 levers for the crane industry

This chapter aims to identify industry 4.0 levers for cranes and crane maintenance in relation to the value drivers from McKinsey. In addition, a discussion is presented for each value driver, in relation to cranes.

Originally, the drivers were meant for manufacturing businesses, but there are several factors and interpretations that may prove efficient in crane applications. Each category of value drivers are discussed in the previous chapter. Levers from resource/ process are identified first;

12.1 Crane resource/process levers

Limiting energy consumption is a very relevant and actual issue in the modern industry. State of the art businesses are very conscious when it comes to their carbon footprint today. Climate changes, pressure from the government, reputation and simply being as climate – friendly as possible drives this development. Many claim that investing in expensive, green technology harms the business, but in reality it will be more expensive to refrain from it. As we have seen in the later years, the rate of nature catastrophes induced by weather and changes on the earth is increasing, causing casualties and huge material damages. Nothing is more expensive than that.

In light of this information, what if it is possible to consume less energy, by utilizing systems that increases efficiency at the same time?

The first industry 4.0 lever in this category is therefore dynamic braking on cranes. What is dynamic braking then?

12.1.1 Dynamic braking

As quoted from Brandon Lyndall, an Konecrane global specialist: “*Dynamic braking uses magnetics and the interplay of variable frequency drives (also known as inverters) and AC motors to slow and stop hoists and bridges.*”

Dynamic braking also has a number of advantages in relation to conventional electromechanical brakes. One of them is improved safety through preventing uncontrolled hoist motions. The control unit of the AC motor senses an over- speed situation, and is able to adjust torque, slowing the motor to control the descending hoist. (Lyndall, 2016)

Another advantage is decreases wear and tear on the brakes. While using the dynamic brakes, electromechanical braking is greatly reduced, which results in less friction on the brake pads, extending their lifetime. In relation to resource / process, this is important, because material usage is lowered; adding further value is the consequence.

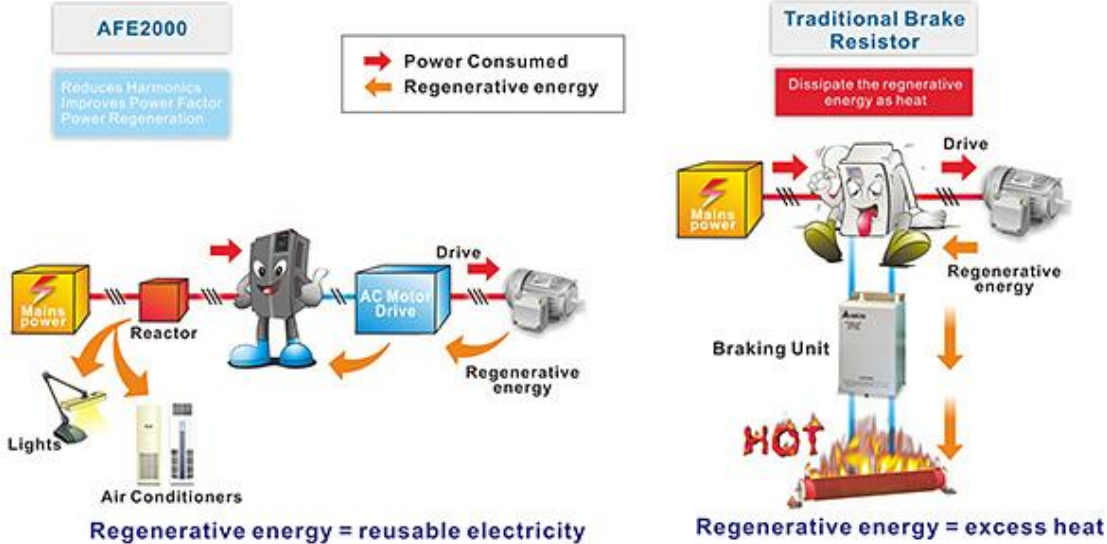


Figure 20 Regenerative vs. traditional braking (Deltaelectronics, 2017)

From the figure, we can see that the energy created from breaking, dissipates as heat. The latest crane designs make use of this energy through the regenerative system. The system uses a generator that catches the energy from the braking, whilst controlling the load. Energy goes back in the drive as AC- current, and is later transformed to DC. This is a clever concept in relation to energy consumption and usage, and ticks of all the right boxes when it comes to utilizing all energy, and reducing carbon footprint.

If this crane has a control system, which is industry 4.0 enabled, the system should be smart enough to make use of this excess energy in the smartest way possible. The energy could be stored in batteries, and used when needed, or routed directly to other parts of the factory/ platform. There is also a possibility to route the energy back to the grid, reducing net power consumption. The options are many. Therefore, this is an industry 4.0 crane lever, which we may name “SmartBraking”

There are also other ways to improve effectiveness for crane usage, one namely the “ideal operator analysis”

12.1.2 Ideal operator analysis

Sadly in some ways, machines are becoming more and more clever, excelling what humans can do by far in many areas. However, there is some comfort in the fact that we have indeed made the machines ourselves. A machine/ robot have the ability to execute a given task to perfection, but the best part is that it can reproduce the results in endless cycles, unlike humans that are unreliable in comparison. (Gregory, et al., 2016) It is not always so easy to see, but modern technology often outsources the human, making the machine control important parameters. Why? Machines are just better.

Modern cars have all sorts of computerized aid systems, making them safer in traffic, correcting the mistakes of humans. Some say newer cars are uninspiring to drive, because they tend to isolate the human from the driving experience. Nevertheless, they are indeed safer. Not many humans can feather the brake pedal perfectly to create an abs motion, reducing brake distance. Tesla now has the technology to use completely self- driving cars. (Tesla autos, 2016) If all cars out in the traffic were autonomous, accident rates would decrease heavily. For example, an autonomous car will never get angry or irritated, attempting a risky takeover.

What can we learn from this in relation to cranes? Cranes are often operated by humans, which does not execute the operation in the most efficient way. (George, et al., 2016) Increased efficiency drives value, so a possible area of improvement in relation to resource/ process is the operation of the crane, or ideal operation. Ideal operation is the best way to execute a task. It has the potential of several advantages like:

- Less resources consumed
- Decreased energy consumption
- Better utilization of crane, frees time
- Increased safety and predictability
- Crane is less strained, decreased chance of operator mistakes- results in a longer lifetime for the crane
- Less need for maintenance, easier to predict maintenance and less unforeseen failures

An ideal operator analysis is done by a connected industry 4.0 computer system, simulating crane activities, monitoring the process variables, weather and other parameters. In this way, the computer system can come up with a suggestion to the ideal operator execution. This can

be fed into an autonomous crane controlling system, to operate a crane without human intervention. It can also be used to train operators, increasing the effectiveness and the other advantages mentioned. This industry 4.0 lever may be named “Ideal Crane operator 4.0”

12.2 Industry 4.0 levers for asset utilization in relation to cranes

12.2.1 Predictive Maintenance

Predictive maintenance influenced by industry 4.0 is clearly an important industry 4.0 lever for the crane industry. (Wang, et al., 2015) Predictive maintenance and new concepts related to cranes is thoroughly discussed in other parts of this paper, mainly in chapter 10. Short and simply, predictive maintenance for cranes reduces downtime, increasing efficiency and HSE standards and reduces maintenance costs. Predictive maintenance combined with industry 4.0, is even more efficient, running interconnected internet devices, and unlocks the possibility to remote control processes and use real- time monitoring. Concepts like Demag StatusControl and SAP Predictive Maintenance and Service Solution are tailored for cranes, and are indeed the future of crane maintenance.



Figure 21 IIoT- a game changer for predictive maintenance (Altizon Systems, 2016)

This figure presents a fictional interface of a predictive maintenance systems connected to the Internet of Things (IIoT), further the advantages the IIoT can give in combination with predictive maintenance:

- *Connected devices and sensors. Manufacturers are building sophisticated, connected gateway products. These products provide standardized ways to talk to the world of sensors.*
- *Ubiquitous data networks. Telecom companies are building better and cheaper data networks with widespread coverage.*

- *The rise of the cloud and the big shift from enterprise to Software as a Service (SaaS) platforms.*
- *Big-Data Technology: The ability to process large amounts of data in a standardized way.*

(Altizon Systems, 2016)

These are factors that are mentioned in chapter 10, but not yet identified as an industry 4.0 lever for the crane industry. Later, in chapter 12.7.2, predictive maintenance is also identified as an industry 4.0 lever for the value driver “Service and aftersales”

12.2.2 Intelligent Task Management

Asset utilization drives value in most companies, especially those who own expensive and large machinery. Depreciating assets, maintenance, running costs and unforeseen failures harm revenue. It is therefore interesting to look at the time aspect, in relation to efficiency when in operation together with idling time. In the previous chapter, resource/ process were discussed, utilizing cranes better with the help of advanced analysis to identify the ideal operator drill. There are also other ways to improve, that impact asset utilization.

A crane is often a relatively expensive device, which depreciates, has running costs and maintenance tied to it. It is therefore important to maximize the usage of the crane, to fully benefit from the investment. Cranes often have different tasks during the time of operation. An unwanted scenario would be if different tasks were stacking in one moment of time, exceeding the crane capacity. This will result in lost revenue, the reason being reduced production speed in the plant due to bottlenecks in the crane department.

An industry 4.0 enabled task manager that is connected to different departments of a plant (production, assembly, sorting, transport etc.), will be able to suggest optimal task timing for different parts of the factory, reducing the problem scenario discussed above. (Tao, et al., 2014) It will outline what task should be executed first, and what should wait, to optimize the production flow. This will be extremely relevant for multidisciplinary manufacturers, running different processes at different times. It is important to note that the task manager will be equally beneficial for all departments of a production/ manufacturing plant. This concept we may name “Task Manager 4.0”

12.3 Industry 4.0 levers for cranes in relation to labor

In this chapter, discussions and solutions to increase efficiency related to labor in cranes are in focus. The optimal solution is to find the correct labor stock, to do the required work with the best quality possible, also taking HSE and HR into account. Industry 4.0 levers are presented below.

12.3.1 Human/ Robot collaboration

In previous chapters, human/ robot collaboration is discussed in general, but how would this work in the crane industry? Sadly enough, having completely robot/ computer controlled cranes would be the optimal solution in a perfect world. As mentioned earlier, machines are already replacing humans because of their versatility. However, we do not live in a perfect world, and human intervention is still sometimes crucial.

An offshore crane, as an example, often operates in seriously harsh conditions, and various situations may occur, situations that computers may not handle well, yet. In this case, human/ robot collaboration is important. A flexible system should be installed on cranes in need for this, so that computer systems can aid humans controlling the crane. This is certainly done on some cranes today, but not in the full extent, utilizing industry 4.0 technology to reap the full benefits of such a system. The advantages of a human/ robot collaborating system with industry 4.0 Technology is:

- Increased control, through the improved information feed. This information may regard weather, crane status, incoming tasks, delays, overloading, over speed, internal temperatures, pressures etc.
- Further resulting in improved safety
- Improved utilization of asset
- Cranes are less strained, results in fewer breakdowns and less maintenance needs
- Drives further value for the company

(Mataric & Clair, 2015)

12.3.2 Remote monitoring

Remote monitoring is one of many advantages of modern predictive maintenance systems. Having the power to continuously monitor processes, and the power to intervene quickly in case of an unforeseen/ sudden event is a great benefit. Remote monitoring is becoming exceedingly important in today's world. If we look at today's offshore oil industry, we are running low on the "easy" oil. (Gjersvik, 2015) New fields are often located far away from shore, in harsh environments and great depths. In such environments, having people on place should be kept to a minimal, because of expenses of having them there and HSE- reasons. (Bokhorst, et al., 2012) Using remote monitoring and control in this case, may prove be a serious contributor to adding value. We should therefore expect great investments in this technology in the years to come.

This is positive news for the crane industry. We have already seen technology linked to remote monitoring for cranes, with systems like "Demag StatusControl" and "SAP Predictive Maintenance and Service solution" The conclusion is that such systems have the potential to raise efficiency in many ways. Maintenance is one of them, as you get more room to plan maintenance work, advances in warning on emerging failures, the possibility to respond immediately to a deviation etc. This, of course lowers the resources spent on maintenance, and increases the quality in execution, and that is exactly what we want. (Demagcranes, 2017)

There are some challenges tied to these systems, as there have been reported some difficulties to obtained the wanted information. It is important to ensure proper training and well-designed intuitive systems. If not, the potential users would not use them, and we are back to square one.

12.3.3 Remote controlling

When it comes to remote controlling of cranes, there are several examples of this in today's market. The solution is a portable control panel that the operator can bring at any time. The point is that the operator does not need to be in the crane, sometimes getting a better overview of the landscape and situation, in addition to safety considerations. A control panel is illustrated in the picture below:



Figure 22 Demag radio control (Demagcranes, 2017)

Although this is a practical and good solution, there are some more possibilities tied to industry 4.0 in relation to remote controlling of cranes. With the proper application of industry 4.0 technology on a crane, such as actuators, servos, internet interface, there is a possibility to remote control a crane while not located on site. There are commercial technologies like Virtual Reality (VR) existing today, so why should it be possible to remote control cranes? Examples of likely advantages remote controlling in this fashion are:

- Crane operations at remote locations, hazardous environments etc. are now more safe, opening new possibilities of where it is possible to operate
- Decreases costs tied to personnel located on site
- Increased flexibility of operation
- Decreased material usage, as cranes does not necessarily need a built- in control tower

For all industries that uses cranes, but especially the oil industry, will reap great benefits using this kind of setup. Keeping the advantages listed in mind, it will clearly add value to the organization. This takes us back to the dilemma and the fact that we are running out of the

easy oil. Technology like this will be a solution to such problems in the future, making it easier to be profitable, safe and unlocking new horizons on the way.

12.4 Industry 4.0 levers for inventories in the crane industry

In the generic chapter we talked about what excessive inventories lead to, and why it is important to keep inventories at a minimum of what you need. This is also highly relevant for the crane industry, and the theory can almost directly be transferred to cranes. In this brief chapter we differentiate between two different types of inventory; spare part and service parts. In this case, spare parts are defined as parts that are not usually replaced, mostly replaced in case of an unforeseen failure of some sort. Service parts are parts that are prone to normal wear and tear, and replaced in certain intervals. (Castanier, et al., 2013) Also, the spare part management philosophy may be different from land- based industries to offshore industries, which will be covered.

12.4.1 Intelligent spare part management

As mentioned earlier, transportation has become very affordable, making large inventories unnecessary and costly. For land based crane installations, the inventories tied to crane spare parts should be near to non-existing, if the crane park is controlled by an industry 4.0 total system like we have seen examples on. This is one of the numerous advantages by implementing such a system; it has so many positive repercussions. A system like this will have total control over the performance and condition of the crane, giving the owners (or system) enough time advance to gently place an order on a replacement part, before an eventual failure. (Karabay & Uzman, 2008) This reduces the need to have an inventory of spare parts, saving costs and room. Spare parts for decent size cranes are often relatively custom and expensive parts. Many companies often fails to consider that such spare parts (gear boxes, engines, generators, planetary gears) must be maintained, even if they are just sitting in storage. Parts need to be lubricated, spun to not get stuck and in some cases updated. In addition, parts have to be stored in certain conditions, for examples in dry and dark areas. All these are factors making large inventories something to avoid if you can. Intelligent spare part management with industry 4.0 technology makes this possible.

When it comes to cranes located offshore, the challenges are bigger when it comes to spare part management. Transporting items offshore is much more cumbersome, expensive and time consuming. From prior learnt knowledge, spare parts like these are usually not kept on platforms at all. (Espset, et al., 2014) There are both pros and cons related to this issue, but the drivers against are safety and space. There is just not enough room to keep a spare part inventories for all of the different systems on a platform.

Because of this, it much more critical if a spare part fails, and is beyond repair. In a worst case scenario, a platform may put to a standstill, with losses in the million dollar range whilst a new part is sourced, produced, transported and installed. Therefore, it is even more important to have industry 4.0 enabled systems that can carefully monitor condition and performance to detect even the smallest of deviations, to make a successful replacement in time. This is what we will name “Intelligent Spare Parts management- ISPM”

12.4.2 Intelligent service parts management

Service parts are often less critical than spare parts in this context, but may become critical without the proper management. With parts like these, it is often more expedient to have a suitable inventory, both in land based and offshore installations. The optimal stock could be found by the industry 4.0 total system, through analysis of previous usage and historian, and condition monitoring. The parts are often not great in size, making them easier to handle and store. Typical service parts for cranes are various bolts, lubricants and fluids, hoses, paint etc. The challenges the industry are having with this type of parts are often tied to management of them, ordering system and stock count. An industry 4.0 system may be the solution to this, optimizing stock and ordering intervals for such parts, using technologies like Würth iBins to count parts in real time. This leads to an always updated system, which is a part of the “Intelligent Spare Parts Management-ISPM”

12.5 Industry 4.0 levers for quality in the crane industry

We have already talked about how quality is a value driver for the modern industry, by getting rid of deficiencies in productions and so forth. But how can we transfer this knowledge to the crane industry?

One of the most important goals for crane manufacturers is to deliver a quality product that is capable to deliver within the specified requirements set by the operator. (Ireland, 2001)

Quality in operation is therefore an important aspect for the crane industry. The quality in operation for a crane is influenced by all parties that are involved:

- Manufacturer
- Supplier (materials, parts etc.)
- Transporter
- Owner
- Operator

Therefore, in this chapter we want to look at two examples of industry 4.0 levers that can lead to improved quality in operation for cranes.

12.5.1 Industry 4.0- a quality booster

Maintenance is one of several factors that influence quality in operation, and indeed a very important factor. Deficient maintenance can lead to several problems during operation for a crane:

- Poor performance- tasks are more time consuming
- Poor condition may lead to HSE- issues
- Downtime causes losses upfront
- Increased resource expenditures (correcting wrongs, extra personnel etc.)

(DAYA, et al., 2009)

By utilizing an industry 4.0 enabled system running connected devices and internet availability, the crane can be analyzed in relation to performance and condition in real- time. How can this help quality in maintenance?

When it comes to planned (proactive) maintenance, there are several boxes to tick to fulfill a quality job. Mainly it relies on having the correct parts available at the right time, with

qualified personnel in place. A total monitoring system will be able to route these tasks in an optimal manner, placing orders on parts in time for them to arrive, scheduling a date that fits the production schedule and ensuring that people with the right skills are able to perform the task.

When it comes to lighter preventive maintenance tasks, like inspections, lubrication, re-tightening, changing service parts, such a system will increase the quality of maintenance in the same way as above. The system will plan upcoming tasks, and call out work orders when needed.

Back to the initial question; how does this have potential to increase quality in maintenance?

- More accurate diagnostics, minimizing rework
- Tasks are done with the correct sort of skills, both helping the quality and resources used, ultimately adding value to the organization
- Better planning of maintenance reduces downtime, adding value through removing unnecessary stops
- Minimized waste of resources (material, equipment, time, personnel)

Maintenance programs enabled to utilize industry 4.0 technologies is clearly a lever that adds value to the organization in many ways, one through increasing quality in maintenance. (Li & Wang, 2016)

12.5.2 Real time problem solving under operation

Real time problem solving is used by Toyota in their production line today. (McKinsey Digital, 2015) The main advantage is the possibility to solve problems as they come on the spot, without costly stops in production to quarantine/ scrap parts or products. This reduces scrap, rework and time consumed, thus increasing quality and driving value further.

Real time problem is a smart concept that should be made possible also in the crane operation. During large and expensive operations, you do not want the crane to stop because a minor problem occurred (electrical, hydraulic, temporary problem)

The newest industry 4.0 technologies offer different forms of self- maintenance on properly interconnected systems, which can be used to solve problems in real time during crane operations. Self- maintenance incorporates a system where intelligent machines are enabled to run inboard diagnostics, and keep its intended function for an extended time. This is done by

sacrificing secondary functions, rerouting signals to prioritized areas, trading off functions etc. For example, a system like this would be able to reroute hydraulic power, electrical power, or use other functions to assist the main function. All this to assure that the intended function is carried out, which is very transferable to cranes under operations.

Having a system enabled to do this, more or less guarantees uptime while most needed, increasing quality in operation.

12.6 Industry 4.0 supply / demand match and time to market levers for the crane industry

Cranes are not usually directly involved in supply/match, but more indirectly. They are often used as a tool in companies that supplies some sort of merchandise, like oil, gas, materials, parts etc. In this way they are not involved in the matching of supply/ demand, but the industry is dependent on cranes to ensure a supply of their merchandise. If the crane on a production platform located on the NCS suddenly fails, the operator may not be able to deliver their agreed quantum of oil/ gas, this resulting in punishment fees and further losses from downtime.

The industry 4.0 levers from supply /match is therefore levers that are discussed in chapters above, in relation to maximizing uptime for the crane, be able to guarantee the production quantum, and to deliver a quality product.

Time to market is also of high relevancy during the development and production phase for a product (in this case; cranes), but the levers are somewhat similar to what we have mentioned in the generic part. It is all about getting an edge on the competition, releasing products with new and efficient technology in advance. To do this, industry 4.0 levers like 3D printing and rapid prototyping may be used during the development phase, to speed up the process.

(McKinsey Digital, 2015) There are extreme examples of companies utilizing these advantages, reducing the development cycle from seven years to one year, so there is no doubt that this is a lever that adds value to the organization. Even if the development phase is more costly, you will release the product earlier, making more money and doing valuable branding for your company. The figure below illustrates the advantages of the time to market principle, and eventual missed opportunities.



Figure 23 Opportunities in market timing (Sopheon Innovation, 2016)

12.7 Service/ aftersales levers for cranes

In a previous chapter we have analyzed what increased quality in operation can result in, and discussed what types of industry 4.0 levers that is relevant for cranes. In this chapter we are going to look cost of operation, and mainly what drives the cost of operation in the crane industry. Furthermore we want to look at industry 4.0 levers that can decrease cost of operation. Using solutions to do this, can open further value potential for the crane industry.

Typical drivers for cost of operations are salaries, material usage, maintenance/ repairs and machine downtime. (McKinsey Digital, 2015) The two last ones are the most relevant in this project.

12.7.1 Remote Maintenance

We have already found an industry 4.0 lever in remote monitoring, which is closely related to remote maintenance. If you are able to assess the performance and condition through remote monitoring, you should also be able to use this information to execute remote maintenance. After assessing the performance and condition, the industry 4.0 total system will analyze the information to make a decision about effective measures, and create an eventual work order. This has several advantages in opposition to traditional inspection methods that rely on humans on site to check condition:

- Minimizes rework- personnel will only do the intervention tasks
- Performance and condition assessment is done in minutes; an on-site check is expensive in comparison, due to work hours, ordering of personnel etc.
- Ensures that all service and maintenance history gets logged, and stored in the historian

(Fujishima & Mori, 2013)

All these factors adds value to the organization by increasing efficiency, and that is why remote maintenance is an industry 4.0 lever for the crane industry.

12.7.2 Predictive maintenance

Predictive maintenance and the use of it in cranes are thoroughly discussed in other parts of the document namely chapter 10, and also in the utilization- chapter. The main factors and advantages for predictive maintenance in the crane industry are:

- Increased planning time and advances in warning time
- Reduces downtime and unforeseen failures
- JIT changes of parts, removing waste by utilizing parts to their fullest
- Highly versatile as every asset are not treated equally, but on an individual basis. In different environment etc. one could not simply treat all assets the same.

(Qiu & Lee, 2002)

All these factors are contributors to added value in the organization and for the cranes, making this an industry 4.0 lever for the crane industry. Note: predictive maintenance programs are best when coupled with industry 4.0 technology, which is thoroughly discussed in other parts of the project.

Service performance is greatly affected by introduction of predictive maintenance, reducing the affiliated costs and resource use, while improving the quality of execution. It is therefore worth mentioning predictive maintenance in this particular value driver.

12.8 Challenges and barriers tied to implementation of concepts

In chapter 7.3.2, a discussion is provided concerning challenges tied to implementation of new technology on process cranes. The big limitation is the crane owners and buyers that do not normally pay more unless a certain technology is required. *“To get the full benefit of the new technology, businesses will have to master many challenges. For many companies, the main hurdles are high investment costs and a not very clear idea of the benefits that will result.”* Says Wilfried Neuhaus Galladé, managing member of the German VDMA’s Association for Materials Handling and Intralogistics. (Weir, 2016)

To make this technology a requirement, it takes either pressure from government instances, or confrontation of the big players in the industry, convincing them to make a requirement. A project like this may be used as leverage and argumentation. (Hopen, 2016)

So these are challenges we already have identified, but what if we look at the identified industry 4.0 levers in particular? In this chapter we look further into this, identifying and discussing challenges, barriers and limitations tied to the levers.

The “ideal operator analysis” is a great way to remove waste, avoid failures under operations and being more time efficient. However, the method demands simulations in forehand to work properly, and a human operator will never obtain the same accuracy as computer. Similar challenges are tied to “robot/ human collaboration”, which also requires a period of training before optimal workflow is found. The buyers of these concepts must be aware of this, and expect some troubles in the start phase, before reaping full benefit of new technology. This also applies for other levers.

History also tells us that humans do not always like to be replaced by robots, so the concept relies on the organizations willingness to embrace change. This to eventually increase efficiency in the organization.

Another problem tied to this technology is the massive computer power that is needed to fuel these concepts, or a predictive maintenance program that incorporates all these technologies. (Tenkorang & Helo, 2016) The computer power and connection of devices should also be rock stable, to ensure a perfectly reliable system. A failure of the system may wreck serious havoc. Luckily, computers are getting rapidly stronger all the time, and are rapidly growing.

Predictive maintenance systems always try to have full control over the asset, thus reducing manual and on- site inspections to a minimum. However, this is not always possible on

cranes, as there are some parts that are challenging to assess via a computer in relation to condition. Examples here are frames, beams, and ropes etc. that are crucial parts of the construction. They often need on- site assessment, done by experts. This is a factor that is important to be aware of in the design of a predictive maintenance system.

Intelligent spare part management is a great way to have total control of spare parts, managing them in a way that are optimal in relation to delivery time and inventory size. However, there will always be challenges tied to spare part management for plants and assets that are located in rural areas, harsh environments and in offshore applications. Especially, sourcing spare parts for an offshore crane may prove to be a challenging task. As the parts must be transported, the time of arrival is not easy to predict, due to unforeseen events of bad weather, transportation overbooking, delaying etc. Having an inventory on the platform is not an option, storage areas are scarce, and it is a hostile environment to store parts in. This will always be a challenge in relation to managing spare parts. (Espset, et al., 2014)

To summarize, these are the identified challenges tied to implementation of new concepts and levers:

- Scary up- front expenditures
- There are no existing requirements tied to new technology
- New technology needs a break- in period where the customers should expect sub-optimal results
- Organizations must be willing to embrace change
- Computer power is may be a limiter, depending on the location
- Some maintenance activities must still be performed on site, by humans
- Spare part management may be challenging and unpredictable, especially in desolate locations.

12.9 Results from industry 4.0 levers for the crane industry

Throughout the last chapters, levers from the industry 4.0 concepts are identified, analyzed, and applied on cranes, both for the crane industry in general and maintenance. The general perception is that this technology is highly adaptable, and can be transferred to the crane industry with great success. Many of the levers identified are not yet in use by any company dealing with cranes, making it challenging to give exact numbers regarding the increases in efficiency, revenue, quality etc. However, we do know approximately the numbers that are applicable for the manufacturing industry, which will give us an impression:

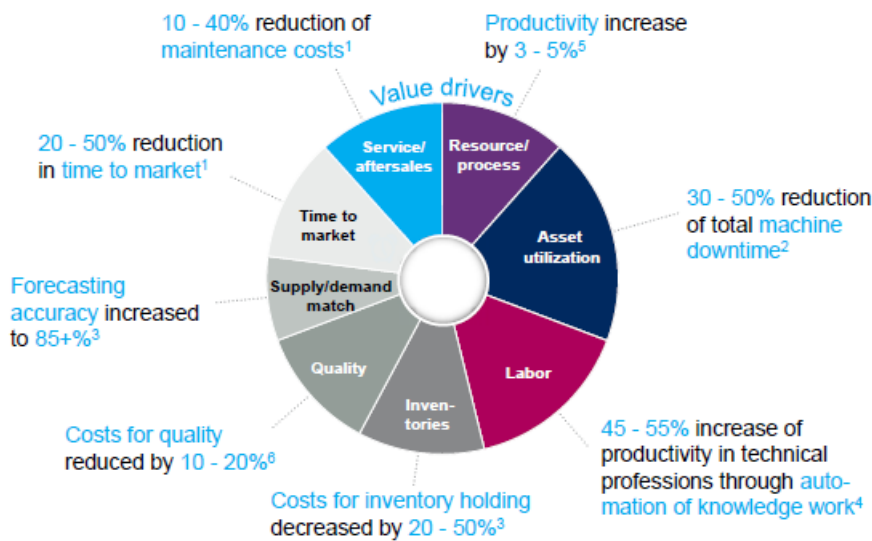


Figure 24 Value drivers (McKinsey Digital, 2015)

This figure presents the value drivers discussed in chapter 10, and shows the possible benefits for each driver, if industry 4.0 levers are implemented correctly in the organization.

It is important to note that these are just pinpoint values, if you are able to utilize the methods to perfection today, but it definitely gives us the impression that there is room for improvement in the crane industry as well. The figure below illustrates the identified levers that are found for each of these value drivers in the crane industry. The upper white boxes are the value drivers, whilst in the blue boxes represents the levers. The two categories “supply/demand” and “time to market” is let out of the illustration, because no unique levers were found for this two. They are however important in general, which is thoroughly explained in the respective chapters.

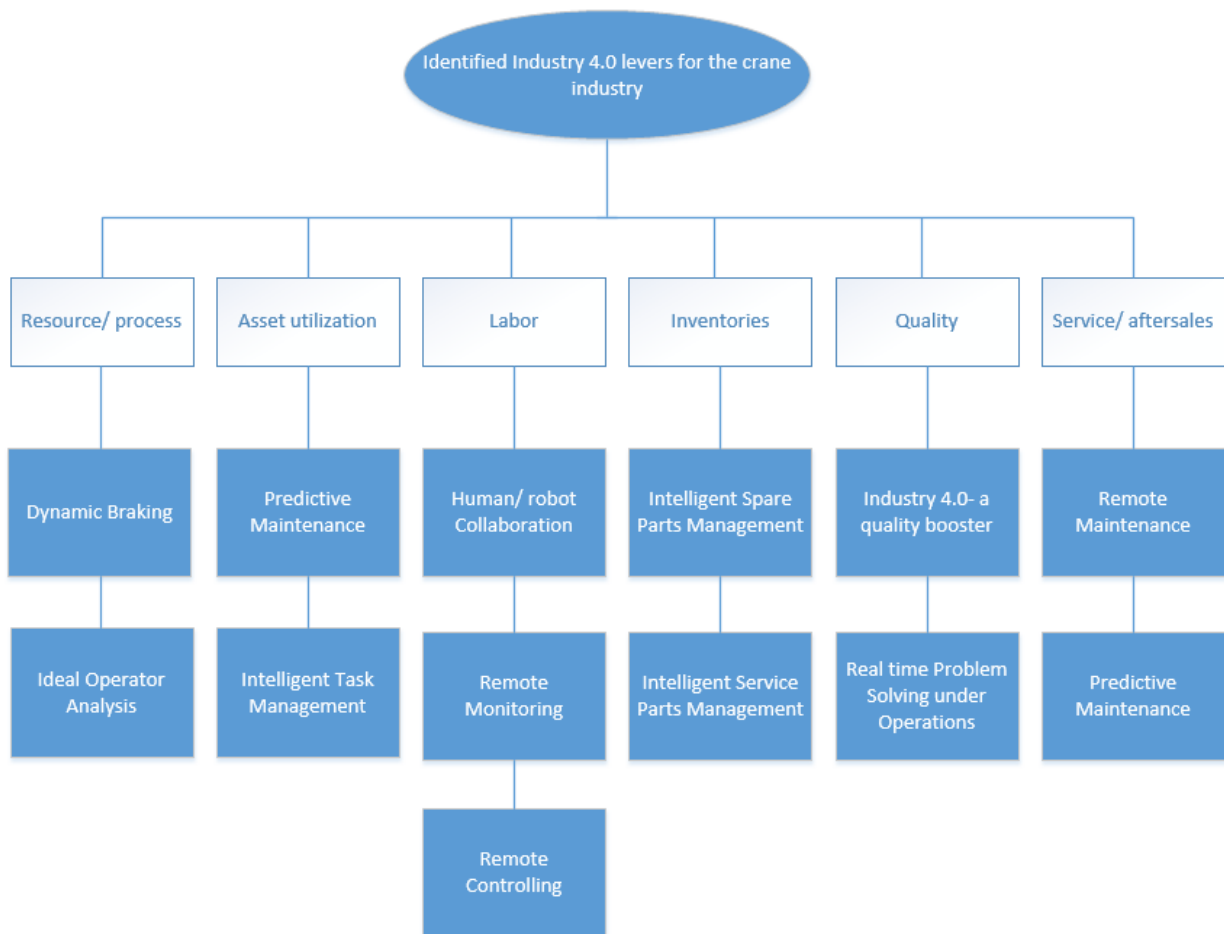


Figure 25 Industry 4.0 levers for the crane industry

12.10 Final words for chapters 11 and 12

Finally, what we have here are actually some of the most central factors that should be included in “total” industry 4.0 system for use in cranes. A “total system” represents a system that takes all disciplines tied to a crane into account. When you first have an industry 4.0 enabled system, running connected devices, there is so much more than maintenance that can be affected positively, and that is some of the beauty of it. One could have a genius product developed and made ready for production, but the result will not turn out great if the machines that are going to produce it are badly maintained. In the same way, having a world class maintenance setup will not help you if your product is lousy. Utilizing a system like this, with the levers identified improves different disciplines at the same time, as every discipline now will work together towards a common goal; increasing efficiency and adding value to the organization.

13 The Next Generation Crane

"As in many other areas, the trend in the crane industry is moving clearly in the direction of intelligent systems in the context of Industry 4.0"- Thomas Kraus, Support Center Director with Künzelsauer STAHL CraneSystems GmbH

To say something about how the future crane would look, we first need to look at the future framework for the crane industry

13.1 Future framework for the crane industry

It is likely to believe that the crane industry will follow the general trends in the industry, and it is not a surprise that the crane industry remains behind the pure manufacturing companies at this stage. In chapter 2, latest trend in the modern industry are discussed, with the industry 4.0 concept that is renewing the traditional factories. Modern factories are emphasizing connected and intelligent systems and devices; we see an explosive increase in robotics and concepts like augmented reality and 3D printing.

International standards will continue to lift the safety level in cranes, which means that stricter requirements will be implemented in the future. (ISO, 2009) As discussed in this paper, predictive maintenance systems and industry 4.0 levers are boosters of safety, so international standards will be an important driver in the time to come. Companies that already have this technology installed when this time comes will have an advantage.

In the project, current predictive crane- maintenance programs utilizing industry 4.0 are identified, like Demag StatusControl and SAP Service Solution. The use of these programs has been somewhat slow, and is mostly used on cranes that have great unit numbers. The goal is that technology should be available for anyone, at a moderate cost.

13.2 Thoughts about the future crane

Now that we have the framework for the road ahead, it should be possible to stipulate a vision of what the future crane would look like.

Following the current trends, the cranes of the future will be better equipped with sensor technology that enables predictive maintenance and industry 4.0 technologies to have their effect. This will result in a crane that is safer, more reliable, have longer lifetime and is a crane that increases the value added to the organization. The apparatus around the crane will be much more complex, including systems that control different industry 4.0 levers like dynamic braking, human/ robot collaboration, remote controlling and more.

Everything becomes more digitized with the introduction to industry 4.0, and direct intervention from humans is kept to a minimum.

Focus on energy efficient cranes will increase, and have already brought us concepts like dynamic braking that regenerates energy through braking. More of this is to come, in relation to material usage, removing waste and increasing efficiency. All of these factors are decreasing the energy usage.

14 Results, conclusion and further work

In this chapter, the project has come to an end, as all tasks are resolved and discussed. A brief walkthrough of the results are presented together with some closing remarks and conclusion. The full understandings of the results are obtained through reading the project report as a whole.

14.1 Results and conclusions

From what is learnt and discussed in this project, the following results and conclusions can be presented:

Cranes and the crane industry have been important to mankind since the establishment of the civilizations as we know it today, and will continue to shape our world in the time to come.

General trends in the modern industry have been identified, which emphasises around a more computerized industry with the introduction of industry 4.0 that are renewing factories into the factories of the future.

Competitive markets and pressurized prices is dominating the crane industry, seeking new and better methods to increase efficiency.

Process cranes and offshore- cranes are struggling with a large amount of corrective maintenance, causing downtimes and losses within organizations. Massive savings are made possible by introduction of new technology and methods. Introduction of this new technology must be induced by requirements from crane buyers, government, standards etc.

In comparison to the pure manufacturing industry, crane industry and crane maintenance is lagging behind in terms of development and use of the next generation maintenance and manufacturing methods.

International standards does not have specific requirements in relation to predictive and industry 4.0 equipment. However, ISO is well known to be a driver for HSE, and as these methods are identified to increase safety, stricter requirements may come in the future.

Predictive maintenance is identified as a good match to overcome today's challenges in the crane industry, in particular process cranes and offshore cranes.

Companies like Demag and Konecranes have already developed predictive maintenance systems with industry 4.0 technology, but the general consensus is that few buyers are investing in these systems yet, especially where the amount of units are low.

Predictive maintenance and the concept of industry 4.0 are identified as a good match, cooperation having several advantages like big data handling in predictive systems, easier decision making, decreased maintenance cost and increased quality of maintenance amongst others.

The newest technologies that drive value for the manufacturing sector are identified and assessed, then adapted for crane use. The results is 13 new industry 4.0 levers that can be used in the crane industry as a part of a predictive maintenance program as an example. The benefits are plentiful, such as up to 10-40% reduction in maintenance costs, up to 30-50% reduction in machine downtime and more. (McKinsey Digital, 2015)

14.2 Further work

Technology develops rapidly in these fields, making new opportunities emerge all the time. Especially in the industry 4.0 sector, there are rapid advances. This is also a driver for developments in maintenance technologies. In a few years, it may be clearer how to utilize this technology in maintenance in general, and crane purposes. The time to come is surely an interesting and exciting time to be in.

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Appendix

Appendix A:

Pre- Study report

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Preface

This Pre- Study Report aims to create an overview of my Master project in Reliability, Availability, Maintainability and Safety. The report will be an important tool to control workload, progress and resources throughout the project.

In the making of this report, I would like to thank supervisor Per Schjøberg and co-supervisor Andreas Marhaug for help and guidance.

The Pre- Study Report has been carried out by Kasper Fuglem Røkke, student at NTNU's department of Production and Quality Engineering.

Trondheim, 07.09.2017

Kasper Røkke

Introduction:

As a part of the two year master programme at NTNU, students are assigned to writing a master thesis in the last semester of the fifth and final year. The master thesis credits 30 study points, and is the only activity during the semester. The Master project consists of a pre- study report, and a final project report, and is carried out independently by the student. Deadline for the final delivery is at February 8.

The Master project is carried out by Kasper Fuglem Røkke, a master student of the two year Subsea Technology programme at the Department of Production and Quality Engineering, NTNU. The report is mainly a theoretical paper, aiming to discuss and present new maintenance concepts and methods.

The problem description is formulated by Associate Professor Per Schjøllberg and Research Assistant Andreas Marhaug at NTNU. The overall theme of the project is *Crane Maintenance*. More specifically the project is related to the industry 4.0 and state of the art maintenance methods, and how one can use this in relation to cranes and crane maintenance.

Per Schjøllberg and Andreas Marhaug has been very helpful under the making of this project, providing me with academic guidance, and assistance in structuring the report. Bård Hopen, Academic leader of Norsk Kranpartner, has also been of great assistance creating a deeper insight in cranes and crane maintenance. I would therefore like to show my appreciation, and send out a big thank you to them!

Description of the project:

Today's companies are facing a series of challenges, experiencing difficulty in increasingly specialized markets and demanding restructuring processes. This is a result from today's competitive markets, and in a local perspective: the historically low oil price. The industry needs countermeasures to prove their place in the market, by utilizing the newest technology and concepts that increases efficiency. Most businesses wants to use less resources, while still maintaining or increasing efficiency and quality. The only way to overcome this challenge is to implement and use better methods. In the middle of all this, there is maintenance, which for many is a necessary evil, especially in terms of cutting costs.

This is where the crane industry comes into play. Cranes have been an important asset for mankind for thousands of years, and is a central part of the modern civilization as we know it today. The crane industry is facing the same challenges as discussed above, and even the largest companies are struggling to sell their products in today's markets. New investments are low, and the products that are sold, are often very basic when it comes to extra equipment and technology (depending on the crane type). This is a mind-set that can be described as "short term thinking". It looks great on the next quarter's finance papers, but in a long term it may not be the most profitable nor safe method.

This Master project focuses on identifying state of the art methods to increase efficiency in the crane industry, especially in relation to maintenance. In addition, the concept industry 4.0 in relation to crane maintenance is central, identifying how this concept can result in added value for crane manufacturers, crane owners, crane users and end product users.

Problem Description:

The problem description is formulated by responsible teacher and supervisor Per Schjølberg and co-supervisor Andreas Marhaug at NTNU. There are nine tasks to be answered, with different weight in workload and complexity. The result is presented in this scientific report. The following questions are to be answered in the report:

10. Give a short presentation of the crane industry, crane maintenance and its purposes
11. Present the relevant and current standards in relation to maintenance and cranes
12. Present the evolution of maintenance as a schematic overview, point out and explain where crane maintenance is located, what the future looks like, and where in the “ladder” industry 4.0 is located
13. Present predictive maintenance, both in relation to industry 4.0 and cranes. Discuss how cranes may benefit from this. Identify today’s best practices in the industry.
14. Present and discuss industry 4.0, and identify and present modern applications of industry 4.0 in the crane industry
15. Identify industry 4.0 value drivers, and use them in context to cranes in a schematic overview.
16. Discuss the value drivers, and how the crane industry and maintenance department will benefit from them
17. Use the information from question 1-7, in particular value drivers to discuss possibilities, barriers and challenges of implementing these concepts.
18. Outline briefly how future cranes and crane maintenance would look in light of

Actors involved in the project:

NTNU:

NTNU is the second largest university in Norway, and is located in Trondheim. NTNU houses approximately 23000 students, which are spread across seven faculties and 48 departments. This project will be carried out at the Department of Production and Quality Engineering (IPK). The department is located under the Faculty of Engineering, Science and Technology. The department has four research groups; Production systems, Production Management, Project and Quality Management, and Reliability, Availability, Maintainability and Safety (RAMS). The department has a close relation to the researcher groups at SINTEF, and a wide industrial network that students benefit of in their project work and master thesis.

Actors from the industry:

Norsk Kranpartner is an engineering company that aims to solve the industries needs when it comes to material- handling. They are one of the leading companies in Norway, possessing engineering competence in both mechanical and electrical constructions. Whether an object shall be lifted, transported, positioned, operated manually or fully automated, it is not a problem, just an exciting challenge. “Nothing is impossible and should be untested”

With their great knowledge and experience within cranes and crane maintenance, they have been of great assistance in this project, creating the needed understanding of the crane industry.

Other than that, it is the intention to make a project that can be relevant for all industry actors. The topic for this project is very actual and relevant for many companies, and feedback from them has been received, showing their interest. The project is open for everyone to read.

Project goal

The main goal and purpose for the project is to identify possible cost- reducing methods for today's industry, mainly focusing on maintenance and crane maintenance. It is important to remember that cost is not just money, but incorporates factors such as safety and quality in products and execution. Being sloppy is something that may prove costly after all. The project has a general approach to the crane industry, but the deeper and longest discussions will propagate around process and offshore cranes in the Norwegian market

To substantiate the main goal and purpose, themes like predictive maintenance, best industry practices, state of the art, evolution of maintenance in cranes, the next generation crane, industry 4.0 value drivers and modern applications of industry 4.0 in cranes are all important. All these themes will be discussed in relation to cranes and crane maintenance, and will be used to assess and propose possible applications, and discuss why these are clever concepts. Another long- term goal is that the results and knowledge from this paper can be used and appreciated by the industry in the future. To break down the goal and purpose, objectives have been defined:

Project Management:

Some sort of Project Management is important to keep track time, workload and progress throughout the semester. It also helps to create an overview of the project at all times. The tools used, and the implementation of this is based on previous experience from project work here at NTNU, and theories related to project management. The methods chosen are WBS, Gantt diagram, and CTR- tables. *"A WBS is a one dimensional breakdown of the project in order to achieve activities which are distinct and manageable"* (Rolstadås, 2014).

The breakdown and activities identified in the WBS are then used into the CTR- tables (Cost, Time, Resources). This is very helpful to manage the work, to ensure an evenly distributed workload throughout the project. The Gantt chart is used because of its simple and understandable nature.

Project plan

The project plan is made to illustrate the different activities in the project, and what they consist of. This is illustrated in the WBS, appendix B. The activities are then put into the CTR- tables, to keep track of workload, time and resources needed. The plan is made by using Microsoft project, and the Gantt diagram is used to easily picture the scheduled progress of the project. It is then easy to evaluate progress during the semester, comparing progress and identifying deviation from the original plan.

In the plan, a full week consists of five working days. A week is estimated to be 37 hours, making this project's workload 37 hours a week, as it is the only activity during this semester. The intention is to have an evenly spread workload across the 21 weeks at disposal. The literature study is a constant process throughout the project, and will end in the middle of December.

It is also important to point out that the direction of this project is not yet 100% settled. The main focus areas of the report are crane maintenance, and applications of industry 4.0 in crane maintenance. New and exciting information about the topic may emerge during the semester, which is why the literature study ends in December. Small deviation from the original plan is therefore likely to occur.

Limitations:

Time:

The problem was handed out the 1st September. The entire project has therefore a timeframe from 1st September to 8th February, calculating 21 weeks with the exception of Christmas holidays. The total workload is of approximately 750 working hours. Most of the workload is concentrated in October, November, December and January. This makes room for an eventual initial underestimate of workload.

Literature:

In a theoretical paper such as this, a large part of the project consists of studying literature and finding the most relevant literature. A challenge here is the amount of time spent on literature study, when keeping in mind a report is also to be written. Finding literature, and more importantly *relevant* literature is crucial to this report. Help and guidance from supervisors here at NTNU will become important in this case.

Interviews and expert statements

To create a deeper insight into the crane industry and maintenance routines, the project relies on expert opinions and statements that comes from interviews and discussions. This is an important moment of the project.

Temporary Literature:

Books:

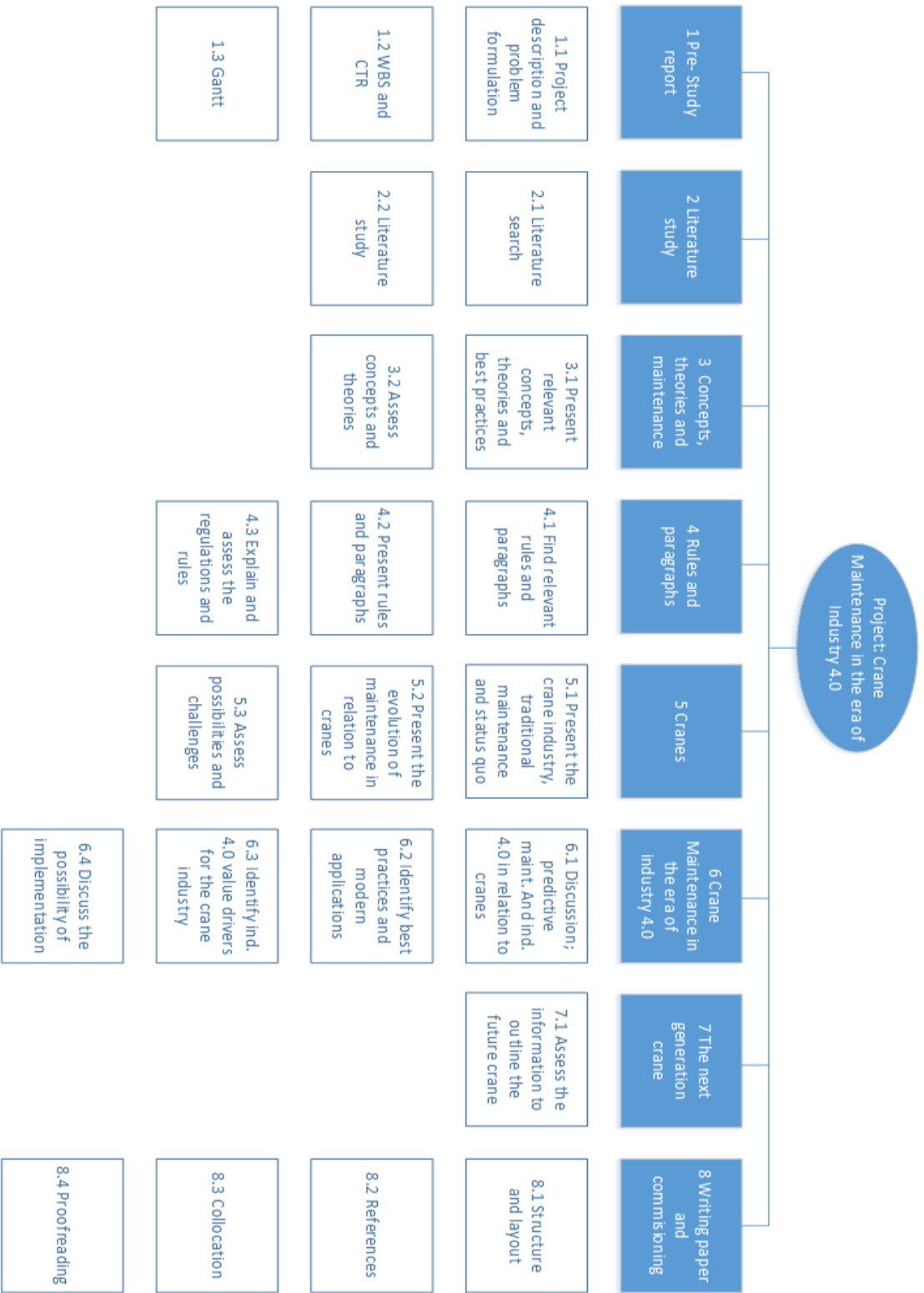
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Appendix A- POS:

Project Overview Statement (POS)	
Project	Date Rev.:
Crane Maintenance	25.09.2016
Resp. person:	
Kasper Røkke	
Problem:	
<p>This Master project focuses on identifying state of the art methods to increase efficiency in the crane industry, especially in relation to maintenance. In addition, the concept industry 4.0 in relation to crane maintenance is central, identifying how this concept can result in added value for crane manufacturers, crane owners, crane users and end product users.</p>	
Goal:	
<p>The main goal and purpose for the project is to identify possible cost- reducing methods for today's industry, mainly focusing on maintenance and crane maintenance.</p>	
Objectives/ targets	
<ul style="list-style-type: none"> - Hand in final report no later than 08.02.2017 - Study, analyse, present and assess the best practices for maintenance concepts and theories. See them in relation to crane maintenance. - Study, analyse, present and assess relevant rules, regulations and paragraphs - Present industry 4.0, and analyse elements for use in combination with crane maintenance - Find value drivers from predictive maintenance and industry 4.0 that can improve the crane industry 	
Success criteria:	
<ul style="list-style-type: none"> - Finished report delivered in time - All tasks are answered in a well manner - Project receives a good grade, and is useful for the industry 	
Assumptions, risks and obstacles	
<p>Assumptions:</p> <ul style="list-style-type: none"> - Supervisors are available for help and guidance - Literature search is executed in a sufficient manner, and the information I use is up to date <p>Risks and obstacles:</p> <ul style="list-style-type: none"> - Other courses are more time- consuming than expected - Estimated workload of project is not correct - Illness, disease or injuries during the semester 	

Appendix B- WBS



Appendix C- CTR:

C.1. Pre- Study Report

Cost, Time and Resources (CTR)			
Project		Date Rev.:	
Crane Maintenance		22.09.2016	
Work package no.:	Work package:	Resp. person:	
1	Pre- study report	Kasper Røkke	
Work task/ packages:			
1.1 Project description and problem formulation 1.2 WBS and CTR 1.3 Gantt			
Goal:			
Identify and analyse the scope of the problem, and create a tool for managing time, resources, workload and progress throughout the project. Use this to allow an even distribution of workload.			
Description of content and work- scope:			
<ul style="list-style-type: none"> - Introduction to the project - Description of project and problem - Project plan - Limitations and scope of work 			
Literature and resources:			
ROLSTADÅS, A. 2014. <i>Praktisk Prosjektledelse</i> , Trondheim, Fagbokforlaget WESTHAGEN, H. 2012 <i>Prosjektarbeid</i> , Gyldendal Microsoft Project 2007			
Method of work			
Identify and analyse task which need to be answered, and make a work- plan considering this.			
Challenges			
<ul style="list-style-type: none"> - Identifying all work packages for the tasks - Some task may be prone to different interpretations, misunderstandings may occur 			
Results:			
A complete pre- study report, used for controlling time, progress and workload throughout the project.			
Estimated time and resources			
Scheduled start:	Scheduled finish:	Person hours:	Duration (days):
01.09.2016	15.09.2016	75	15

C.2. Literature Study:

Cost, Time and Resources (CTR)			
Project			Date Rev.:
Crane Maintenance			22.09.2016
Work package no.:	Work package:		Resp. person:
2	Literature Study		Kasper Røkke
Work task/ packages:			
2.1 Literature search 2.2 Literature study			
Goal:			
Identifying, reading and analysing relevant literature to have the possibility to solve the tasks given.			
Description of content and work- scope:			
List of relevant literature			
Literature and resources:			
<ul style="list-style-type: none"> - Supervisors Per Schjøberg and Andreas Marhaug - Databases at NTNU - Library - Previous projects 			
Method of work			
<ul style="list-style-type: none"> - Search in BIBSYS, Scopus, Google Scholar and other databases - Recommendations from supervisors, and relevant books found at library - Reading literature after literature search, concentrate on the most relevant findings 			
Challenges			
<ul style="list-style-type: none"> - Overload of information may cause trouble separating relevant literature from irrelevant - Time to read and analyse, keeping in mind a report is also to be written 			
Results:			
A list of relevant literature that can be applied to the problems described in the project			
Estimated time and resources			
Scheduled start:	Scheduled finish:	Person hours:	Duration:
15.09.2016	15.12.2016	100	

C.3. Concepts, theories and maintenance

Cost, Time and Resources (CTR)			
Project			Date Rev.:
Crane Maintenance			22.09.2016
Work package no.:	Work package:		Resp. person:
3	Concepts, theories and maintenance		Kasper Røkke
Work task/ packages:			
3.1 Present relevant concepts, theories and best practices			
3.2 Assess concepts and theories			
Goal:			
To present a description and evaluation of the most relevant concepts, theories and practices, to ensure proper development and relevancy in the project.			
Description of content and work- scope:			
<ul style="list-style-type: none"> - Presentation and description of today's best practices in crane- maintenance - Figures for easy understanding of concepts and theories - Evaluation of the theories and concepts relevancy 			
Literature and resources:			
<ul style="list-style-type: none"> - Relevant literature found in literature study (books, articles, standards) - Supervisors at NTNU - Help from industry actors 			
Method of work			
<ul style="list-style-type: none"> - Literature study - Consulting supervisors and key- persons in the industry 			
Challenges			
<ul style="list-style-type: none"> - Time available - Choice of relevant and best suited theory for solving given problems 			
Results:			
Assessment, description and understanding of best practices for crane maintenance			
Estimated time and resources			
Scheduled start:	Scheduled finish:	Person hours:	Duration (days):
01.10.2016	09.10.2016	52,5	9

C.4. Rules and Paragraphs

Cost, Time and Resources (CTR)			
Project			Date Rev.:
Crane Maintenance			22.09.2016
Work package no.:	Work package:		Resp. person:
4	Rules and Paragraphs		Kasper Røkke
Work task/ packages:			
4.1 Find relevant rules and paragraphs 4.2 Present rules and paragraphs 4.3 Explain and assess the regulations and rules			
Goal:			
Presenting and assessing the most important rules and paragraphs concerning the problems. This to ensure that the eventual implementations of theories and concepts have a real- world anchoring.			
Description of content and work- scope:			
<ul style="list-style-type: none"> - Presentation of the relevant rules and paragraphs to crane maintenance, industry 4.0 and implementation of concepts. - Assessing of these 			
Literature and resources:			
<ul style="list-style-type: none"> - Supervisors at NTNU - Standards, rules and regulations found in literature study 			
Method of work			
<ul style="list-style-type: none"> - Literature study of the rules and paragraphs - Consulting supervisors 			
Challenges			
<ul style="list-style-type: none"> - Time available - Proper understanding of the rules and paragraphs, to make qualified decisions on relevancy to project 			
Results:			
Description and assessment of relevant rules and paragraphs relevant to the project			
Estimated time and resources			
Scheduled start:	Scheduled finish:	Person hours:	Duration (days):
10.10.2016	20.10.2016	60	10

C.5. Cranes

Cost, Time and Resources (CTR)			
Project			Date Rev.:
Crane Maintenance			22.09.2016
Work package no.:	Work package:	Resp. person:	
5	Cranes	Kasper Røkke	
Work task/ packages:			
5.1 Present the crane industry, traditional maintenance and status quo			
5.2 Present the evolution of maintenance in relation to cranes			
5.3 Assess possibilities and challenges			
Goal:			
To give a thorough description of cranes and crane- maintenance, and present a qualified view on how the emerging cost- focus will crane maintenance			
Description of content and work- scope:			
<ul style="list-style-type: none"> - Description and views on work tasks - Figures and models for visualizing - Assessment of current maintenance methods for crane purposes 			
Literature and resources:			
<ul style="list-style-type: none"> - Relevant literature found in literature study (books, articles, standards) - Supervisors at NTNU - Key- persons in the industry 			
Method of work			
<ul style="list-style-type: none"> - Literature study - Applied theory from literature study - Consulting - Experience from fellow students 			
Challenges			
<ul style="list-style-type: none"> - Time available - Choice of relevant and best suited theory for solving given problems - Objectiveness in discussion 			
Results:			
A description and assessment of the most important elements from the crane industry, in relation to "state of the art" maintenance and best practices.			
Estimated time and resources			
Scheduled start:	Scheduled finish:	Person hours:	Duration (days):
21.10.2016	05.11.2016	75	12

C.6. Crane Maintenance in the era of industry 4.0

Cost, Time and Resources (CTR)			
Project			Date Rev.:
Crane maintenance			22.09.2016
Work package no.:	Work package:		Resp. person:
6	Crane maintenance in the era of industry 4.0		Kasper Røkke
Work task/ packages:			
6.1 Discussion; predictive maint. and ind. 4.0 in relation to cranes			
6.2 Identify best practices and modern applications			
6.3 Identify ind. 4.0 value drivers for the crane industry			
6.4 Discuss the possibility of implementation			
Goal:			
Find new possibilities and cost effective ways by utilizing moments from predictive maintenance and industry 4.0. Identify value drivers for the crane industry			
Description of content and work- scope:			
<ul style="list-style-type: none"> - Description of key elements in industry 4.0 and predictive maintenance - Discussion of possibilities and challenges in implementation - Relevant value drivers from industry 4.0 			
Literature and resources:			
<ul style="list-style-type: none"> - Relevant literature found in literature study (books, articles, standards) - Supervisors at NTNU 			
Method of work			
<ul style="list-style-type: none"> - Applied theory from literature study - Consulting supervisors - Argumentation and evaluation 			
Challenges			
<ul style="list-style-type: none"> - Time available - Choice of relevant and best suited theory for solving given problems - Adequate understanding of theory, for maintenance applications - Industry 4.0 is a relatively new concept, literature and access may be limiting 			
Results:			
Value drivers for cranes, insightful discussions and analysis of challenges in relation to implementation			
Estimated time and resources			
Scheduled start:	Scheduled finish:	Person hours:	Duration (days):
06.11.2016	05.01.2017	262,5	60 incl. vacation

C.7. The next generation crane

Cost, Time and Resources (CTR)			
Project			Date Rev.:
Crane Maintenance			22.09.2016
Work package no.:	Work package:		Resp. person:
7	The next generation crane		Kasper Røkke
Work task/ packages:			
7.1 Assess the information to outline the future crane			
Goal:			
Be able to use previous knowledge to outline the future within cranes and crane maintenance			
Description of content and work- scope:			
<ul style="list-style-type: none"> - Analyse of articles related to the future - Assessment of information to use - Outline the future crane - Figures and models to visualise 			
Literature and resources:			
<ul style="list-style-type: none"> - Supervisors at NTNU - Relevant literature from literature study 			
Method of work			
<ul style="list-style-type: none"> - Evaluation and argumentation - Consulting - Applied theory from literature study 			
Challenges			
<ul style="list-style-type: none"> - Time available - Choice of relevant and best suited theory for solving given problems - The success of the task depends on information available and applicability 			
Results:			
Thoughts about the future crane, possible challenges, advantages etc.			
Estimated time and resources			
Scheduled start:	Scheduled finish:	Person hours:	Duration (days):
06.01.2017	20.01.2017	75	14

C.8. Writing paper and Commissioning

Cost, Time and Resources (CTR)			
Project			Date Rev.:
Crane Maintenance			22.09.2016
Work package no.:	Work package:		Resp. person:
8	Writing paper and Commissioning		Kasper Røkke
Work task/ packages:			
8.1 Structure and layout 8.2 References 8.3 Collocation 8.4 Proofreading			
Goal:			
A scientific report that fulfils university standards, and gives answers to the problems given.			
Description of content and work- scope:			
<ul style="list-style-type: none"> - Organization of the report (layout/ structure/ references) - Final report ready to deliver 			
Literature and resources:			
<ul style="list-style-type: none"> - Microsoft Word 2010 - Microsoft Project 2007 			
Method of work			
Challenges			
<ul style="list-style-type: none"> - Time could get scarce in the end of the project - Computer and software issues 			
Results:			
A scientific report for the Master project			
Estimated time and resources			
Scheduled start:	Scheduled finish:	Person hours:	Duration (days):
21.01.2017	08.02.2017	50	17

Appendix D- Gantt:

