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TAMPERE UNIVERSITY OF TECHNOLOGY

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REMOTE MONITORING FOR AUTOMATED CONTAINER TERMINALS

Master's thesis

Examiners: Professor Jose Martinez Lastra and Doctor of Science in Technology Jani Jokinen
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ABSTRACT

TEEMU HÄRKÖNEN: Remote monitoring for automated container terminals
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This master's thesis studies the possibilities of remote connections and remote monitoring for the cargo handling solution provider Kalmar. Kalmar's equipment is used in critical container terminals, where downtimes or delays are not tolerated, which is why it is important to provide reliable machines. This thesis studies, whether monitoring data could help in creating more reliable machines, and how different stakeholders could benefit from remote monitoring. During this master's thesis work, a demo version of a remote center was built at Kalmar's Tampere Competence Center. New telecommunication technologies, such as URLLC and LoRa, which may prove to be helpful in establishing wireless remote connections in container terminals, are also discussed in the case study.

The theoretical part of this study mainly consists of a literature review, focusing on remote connections and monitoring, Industrial IoT (Evans, Annunziata 2012, Kunttu, Kiiveri 2012, Jurvansuu, Ailisto et al. 2013), data visualization (Becker, Mottay 2001, Väänänen-Vainio-Mattila, Wäljas 2009) and maintenance (de Faria Jr., Costa et al. 2015, Peng, van Houtum 2016). The case study of the thesis is based on literature studies and empirical data. The empirical data was collected by participating in Kalmar's development events and by building a demo version of the remote center. First-hand observation on Kalmar's products and operations was done during a summer internship and in informal discussions with Kalmar's engineers and managers.

This thesis suggests that remote connections and remote monitoring would benefit Kalmar and other stakeholders involved. A physical remote center is not necessarily needed in order to monitor equipment globally, but it could have significant marketing value. Wireless communication technologies related to remote connections and monitoring could offer more flexible deployment of cranes and cost savings. It seems that remote connections and monitoring could provide a lot of new business possibilities for Kalmar.

TIIVISTELMÄ

TEEMU HÄRKÖNEN: Automatisoitujen konttiterminaalien etämonitorointi
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Tämän lopputyön tarkoituksena on tutkia mahdollisuuksia, joita etävalvonta ja etäyhteydet tarjoavat konttien käsittelyn ratkaisuja toimittavalle Kalmarille. Kalmarin tuotteita käytetään kriittisissä konttiterminaaleissa, joissa seisokkeja tai viiveitä ei suvaita. Tämän vuoksi Kalmarille on tärkeää, että heidän laitteensa ovat hyvin luotettavia. Tämä lopputyö tutkii, voisiko etävalvontadataa hyödyntää laitteiden luotettavuuden parantamisessa, sekä sitä, kuinka eri sidosryhmät voisivat hyötyä etäyhteyksistä ja etävalvonnasta. Lopputyön aikana Kalmarin Tampereen Teknologia- ja osaamiskeskukseen rakennettiin demoversio etävalvontakeskuksesta. Lopputyö tutkii myös uusia langattomia tietoliikennetekniikoita, jotka voisivat olla hyödyllisiä etäyhteyksien muodostamisessa.

Lopputyön teoriaosuus koostuu kirjallisuustutkimuksesta, joka keskittyy etäyhteyksiin, etävalvontaan, teolliseen internetiin (Evans, Annunziata 2012, Kunttu, Kiiveri 2012, Jurvansuu, Ailisto et al. 2013), datan visualisointiin (Becker, Mottay 2001, Väänänen-Vainio-Mattila, Wäljas 2009) ja kunnossapitoon (de Faria Jr., Costa et al. 2015, Peng, van Houtum 2016). Lopputyön tapaustutkimus pohjautuu kirjallisuustutkimukseen sekä empiiriseen tietoon. Empiiristä tietoa kerättiin osallistumalla Kalmarin tuotekehitykseen liittyviin tapahtumiin sekä rakentamalla demoversio etävalvontakeskuksesta. Ensikäden havainnointia Kalmarin tuotteisiin ja toimintaan tehtiin kesäharjoittelun aikana sekä epämuodollisten keskustelujen kautta Kalmarin insinöörien ja esimiesten kanssa.

Tämän lopputyön perusteella voidaan sanoa, että etäyhteyksistä ja etävalvonnasta olisi hyötyä Kalmarille sekä sen sidosryhmille. Fyysinen etävalvontakeskus ei välttämättä ole teknisestä näkökulmasta tarpeellinen laitteiden valvonnan mahdollistamiseksi, mutta sillä voisi olla merkittävä markkinointiarvo. Langattomat etäyhteksiin ja –valvontaan liittyvät tietoliikennetekniikat voisivat mahdollistaa kustannussäästöjä sekä joustavamman laitteiden käyttöönoton. Työn tuloksena voidaan todeta, että kontinkäsittelylaitteiden etäyhteydet ja etävalvonta voisivat luoda uusia liiketoimintamahdollisuuksia Kalmarille.

PREFACE

When I was starting this thesis work, one of my colleagues said: “The most important thing in the master’s thesis is that you do it.” I am happy to say that the most important part is now done.

I would like to thank Pekka Yli-Paunu from Kalmar for offering me the topic for this master’s thesis and for his help during this process. Also Jyrki Kouhia from Kalmar deserves my thanks for providing me material for the thesis.

Doctor of Science Jani Jokinen, the supervisor of this thesis, I would like to thank you for the feedback and help.

I would like to thank my mother and father for the support and encouragement they have given me during my whole life. My father has had a great influence on the choices I have made during my studies, and I am truly grateful for the tips and advice he has given me. Also my brother and friends deserve my thanks for all of the discussions and good moments during my studies.

Last but definitely not least, I would like to thank my girlfriend for the great support during my studies and for proofreading this thesis. This would have been a lot harder and more time consuming without her help.

Tampere, 1.3.2017

Teemu Härkönen

TABLE OF CONTENTS

TERMS AND ABBREVIATIONS

API	Application Programming Interface
APN	Access Point Name
APT	Advanced Persistent Threat
ASC	Automated Stacking Crane
AutoRTG	Automated Rubber Tired Gantry
BDR	Backup and Disaster Recovery
CBM	Condition Based Maintenance
CRM	Customer Relationship Management
DLP	Data Loss Prevention
ERP	Enterprise Resource Planning
GPS	Global Positioning System
HDMI	High Definition Multimedia Interface
Industrial IoT	Industrial Internet of Things
IoT	Internet of Things
KPI	Key Performance Indicator
LAN	Local Area Network
LoRa	Long Range
LPWAN	Low-Power Wide-Area Network
LTE	Long Term Evolution (4G)
OBD	On-Board Diagnostics
PC	Personal Computer
PLC	Programmable Logic Controller
QR code	Quick Response Code
RFID	Radio Frequency IDentification
RPM	Revolutions Per Minute
RTG	Rubber Tired Gantry
SDK	Software Development Kit
SFTP	SSH File Transfer Protocol
TCP	Transmission Control Protocol
TDMS	Technical Data Management Streaming
UI	User Interface
URLLC	Ultra-Reliable and Low-Latency Communications
UX	User Experience
VPN	Virtual Private Network
WAN	Wide Area Network

1. INTRODUCTION

This thesis is a study on remote monitoring and data collection of container handling equipment manufacturing company, Kalmar. The thesis focuses on how Kalmar could utilize established remote connections to their customer's container handling machines and data collected from the machines. The first chapter includes an introduction to Kalmar and container handling business as well as a preface for the research made during this thesis work. The theoretical part of the thesis is mostly a literature study of topics related to remote monitoring, data visualization and industrial maintenance. The empirical part of the thesis is a case study of Kalmar's current remote connections and remote monitoring data collection technologies.

The second chapter gives an introduction to remote monitoring in general, discusses how remote monitoring can be implemented in an industrial environment and what the concept of a remote center means. Remote monitoring is an essential part of the Industrial Internet of Things concept, which is also discussed in the second chapter. Different parts of an organization and customers can benefit from the collected remote monitoring data. These possible benefits are discussed in third part of the second chapter. The last part of the chapter discusses data security concerns related to remote monitoring.

The third chapter presents data monitor visualization and topics related to usability. Monitor layout and its elements are discussed, as well as tools for visualizing the data. The chapter also discusses user experience in general, and explores how user experience should be taken into account when designing data monitors and remote monitoring centers.

Industrial maintenance is one of the most common applications for remote monitoring data. The fourth chapter introduces industrial maintenance in general, defines the concepts of corrective, preventive, predictive, proactive and condition based maintenance and discusses, how remote monitoring data could be utilized to implement predictive maintenance, for example.

The fifth chapter is a case study of Kalmar's remote connections and remote monitoring data collection technology. Firstly, the chapter gives an introduction to automated container terminals to clarify what is monitored and where the data is coming from. The chapter also presents the demo version of the remote center, which was built at Kalmar's Tampere Technology and Competence Center during this thesis work, and illustrates what is included in the room and what does it look like. The chapter also shows how the data is acquired from Kalmar's customer equipment and explores new technologies that could be used in automated container terminals in the future to collect data and control cranes remotely. Such technologies are, for example, URLLC and LoRa communication technologies, which are being tested at Kalmar. Current data visualization in Kalmar Cloud is also presented with authentic examples. Finally, the last part of the chapter gives a vision and future insights for remote center and remote monitoring business.

1.1 Kalmar briefly

Kalmar provides cargo handling solutions to ports, terminals, distribution centers and heavy industry. Kalmar is a forerunner in terminal automation and energy-efficient container handling, and it offers cargo handling equipment, automation, software and services. The equipment portfolio includes straddle and shuttle carriers, terminal tractors, yard cranes, ship-to shore cranes, reach stackers, empty container handlers and forklift trucks. (Kalmar 2016)

At the end of 2015, Kalmar had over 5 200 employees in 30 countries, including United States, Malaysia, Sweden, China, Finland, Poland, Spain, India and Netherlands, and totaled 1,6 billion euros in sales. Kalmar is a part of Cargotec, shares of which are quoted on Nasdaq Helsinki Ltd. Cargotec employs approximately 11 000 people and its sales totaled approximately 3,7 billion euros in 2015. (Kalmar 2016)

1.2 Research topic

Kalmar's cargo handling equipment is used, for example, in critical container terminals, where customers do not tolerate long downtimes or delays. For this reason, it is important for Kalmar to ensure that their customers have reliable and working machines. Therefore, it is necessary that the equipment can be constantly overseen and monitored.

During this master's thesis work, a demo version of Kalmar's first remote center was built. This demo version is intended as a first step in creating an environment that makes it possible to remotely monitor global equipment from Kalmar's Tampere Competence Center. The topic for this master's thesis is to research how the remote center, remote connections, monitoring data and related technologies can be utilized in Kalmar's business.

1.3 Research methods

The research starts with a theoretical part that consists mainly of a literature review of topics and terms related to subject area. The theoretical part mainly focuses on available technologies related to industrial remote monitoring, remote connections, Industrial Internet of Things, data visualization and maintenance.

The vision of remote monitoring introduced in this thesis is based on literature studies and empirical data. The empirical data was collected by participating Kalmar's development events related to digitalization and by building a demo version of the remote center in practice. First-hand observation on Kalmar's operations and products was done during a summer internship and meetings related to developing data collecting, remote connections and remote monitoring. These meetings took place in winter 2016-2017. I also had informal discussions with anonymous Kalmar employees, who were working as engineers and managers on Kalmar's research and development organization during the writing of this thesis.

1.4 Limitations to the scope

This thesis mainly focuses on the possibilities that remote connections, monitoring and collecting machine data could offer for Kalmar in container handling business generally, as well as from the point of view of service, maintenance, R&D, sales and other Kalmar's organizations. Another important topic is to research how data could practically be presented and visualized in the remote center. The remote center demo version was built during this thesis work, but a large scale remote center will be built in the future. Therefore, this thesis gives a vision for the future remote center and the new business possibilities it could provide.

This thesis will not cover the details on how sensors are measuring data. However, data transferring technologies from the sensors to Kalmar Cloud now and in the future are discussed in the case study. For example, URLLC and LoRa are introduced as new technologies for data transfer.

2. REMOTE MONITORING

Remote monitoring in container terminal industry basically means that equipment like AutoRTGs (automated rubber tired gantry) provide usage data, which is collected through a remote connection and compiled into easy-to-read web views and customer reports that are available through a secure online web portal for the customer and the manufacturer. Through the web portal the customer and the manufacturer are able to see historical data of the equipment in near real time. (Automation.com 2014)

The historical data consists of machine operations and performance that enables operators to better understand the condition of crucial components in a machine. Operators can see how long and under what conditions a specific component has been operating and compare it to components in other machines. By using analytic tools operators can then give estimates on how long the component will still last. Utilizing these estimates necessary maintenance work can be done early enough to avoid costly equipment downtime. (Evans, Annunziata 2012)

Remote monitoring can also be used to optimize maintenance costs not only by predicting the situation of one machine but the situation of the whole fleet. A combined view across machines and individual components can provide a line of sight on the status of the equipment and make it possible to deliver optimal number of right parts to right place at the right time. (Evans, Annunziata 2012)

Chapter 2.1 discusses the concept of a remote center and chapter 2.2 the connection between Industrial IoT and remote monitoring. Furthermore, the benefits and possibilities of remote monitoring and data security are explored in chapters 2.3 and 2.4.

2.1 Remote center

Connecting data, machines and people is one of the key elements of remote monitoring. The goal of a remote center is to achieve that connection by providing real time data dashboards to technical experts in a central location. A clear benefit of having a central remote center is that a team of experts is in one location, which helps the team to communicate easily and quickly to solve any upcoming problems and provide optimal support to customer remotely. This way unplanned equipment downtime can be reduced and productivity improved. (Penfold 2016)

Remote centers are utilized on a daily basis to monitor that all monitored machines are up and running, and to advice service people and customers when if something needs to be fixed. Deeper data analysis is done automatically by utilizing analytical algorithms. (Penfold 2016)

Remote centers do not necessarily have to be physical rooms located in a company’s headquarters. A remote center can also be a virtual remote center, which technical experts are connecting to from anywhere in the world through their laptops. Essentially, the target is to have everything connected, so a room called ‘remote center’ is not a must. A remote center room, however, can be a great way to visualize for the customer what they are paying for, when a company is providing remote services. It is easier to show what is monitored, what kind of data is collected and how the whole system works on bigger and maybe interactive screens. As mentioned before, a central room can make it easier for the experts to communicate with each other. Communication between the experts is essential, as they have a lot of critical tacit knowledge of the monitored machines, which is needed to fix any occurring problems.

2.2 Remote Monitoring as a part of Industrial IoT

There are several different names for the Industrial IoT, such as Industrial Internet, Internet of Things and Internet of Everything. These names all refer to the same phenomenon with a slight difference, but in this thesis I refer to it as Industrial IoT.

Jay Ireland, (Ireland 2015) the President and CEO of GE Africa, defines the Industrial Internet as follows:

> ”The industrial Internet draws together fields such as machine learning, big data, the Internet of things and machine-to-machine communication to ingest data from machines, analyze it (often in real time), and use it to adjust operations.” (Hoffman, Frenk 2015)

In container handling business Industrial Internet of Things can be imagined as a world where every container handling machine is interconnected in the automated container terminal and throughout the logistical chain from the point of shipping to the point of delivery. Interconnectivity could also include the owner of delivered goods, the shipping container terminal, the shipping company, the receiving container terminal and land transportation companies. (Pihkala 2016)

Industrial IoT provides a great amount of opportunities to optimize delivery efficiency and reliability in container handling business. Machine service, maintenance and support are the areas where the quickest improvement could achieved. (Pihkala 2016)

Industrial IoT consists of several parts, and remote monitoring is an essential part of the concept. The following figure 2.1 illustrates the concept of Industrial IoT and shows how remote monitoring is connected to it.

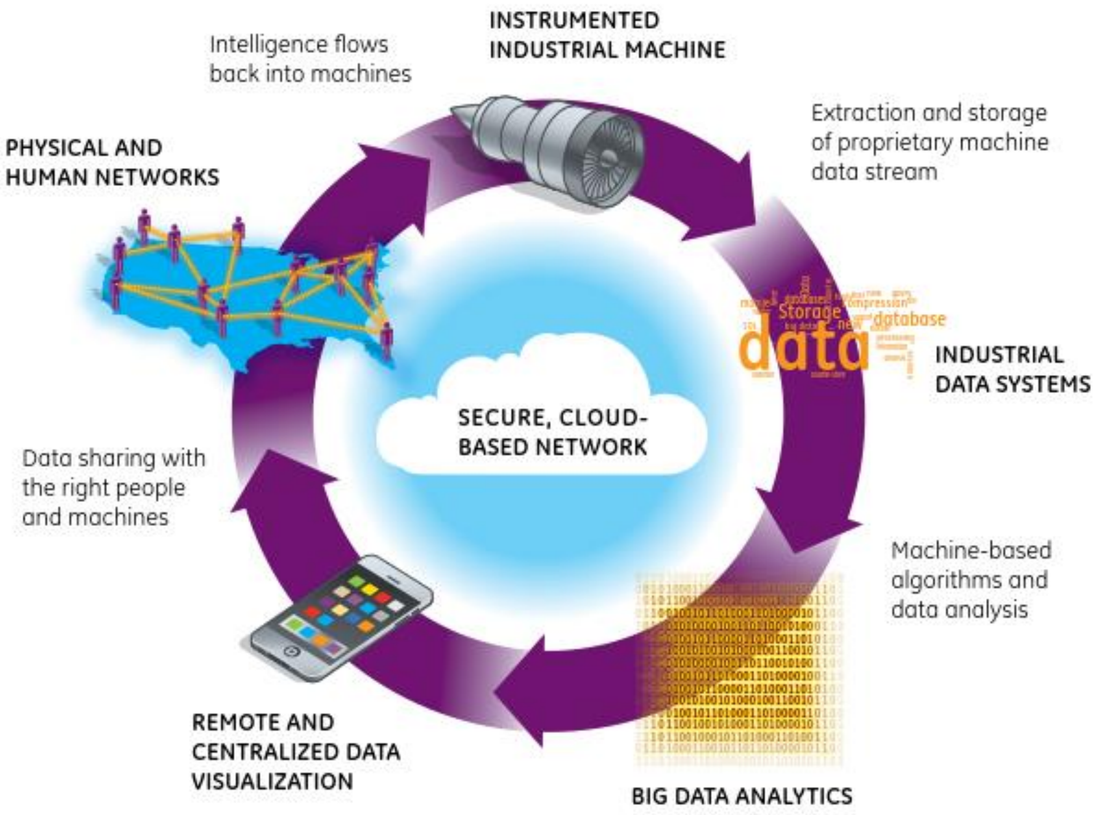

***Figure 2.1** Remote and centralized data visualization is an essential part of Industrial IoT concept. (Evans, Annunziata 2012)*

Basically the purpose of any IoT device is to connect and communicate with other IoT devices or applications. To make this communication possible for the devices, an IoT platform is needed. The purpose of an IoT platform is to fill the gap between the device sensors and data networks. (Singh 2016)

Utilizing a ready-made commercial IoT platform might be an option, which could help avoid unnecessary work. However, the decision of using a too generic or closed platform can reduce the benefits gained from IoT. Genericity in itself is something to strive for, but advantages for an industrial manufacturer can be low, if commissioning and application development means a huge amount of tailoring and configuration as well as complicated maintenance work. For industrial manufacturers it is important to keep the core application in their own hands. (Elo 2016)

There are several commercial IoT platforms available on the market, such as IBM's Bluemix, Microsoft's Azure IoT Suite, PTC's ThingWorx and Amazon's AWS IoT. At the time of the writing this thesis, Siemens has recently launched an IoT platform for industrial applications called MindSphere – Siemens Cloud for industry. I am going to introduce MindSphere here as an example in order to give a better illustration of what an industrial IoT platform is. Figure 2.2 below roughly illustrates the main components of MindSphere.

Figure 2.2 *MindSphere is a commercial industrial IoT platform. (Veijola 2016)*

MindSphere is a data hosting platform that allows manufacturers to connect devices and equipment from shop floor to a cloud and to securely store operational data that has been collected from the industrial equipment. MindSphere is specifically designed to connect equipment in an automated production environment, such as an automated car factory or an automated container terminal. It is not designed for connecting individual products, such as cars or wind turbines. (Naujoks 2016)

Equipment and devices are connected to the cloud through a gateway device. A gateway is basically a PC which is gathering and pre-processing the data before it is sent to the cloud. (Greenfield 2016)

Manufacturers can utilize MindSphere to monitor their machines, devices, plants and shop-floor equipment globally. Monitoring data can be used, for example, to predict maintenance needs and to optimize resource utilization by using different applications that have been developed for MindSphere by Siemens and other developers. Manufacturers are also able to create their own applications and dashboards due to open application interfaces. Figure 2.3 below illustrates data utilization in MindSphere. (Naujoks 2016)

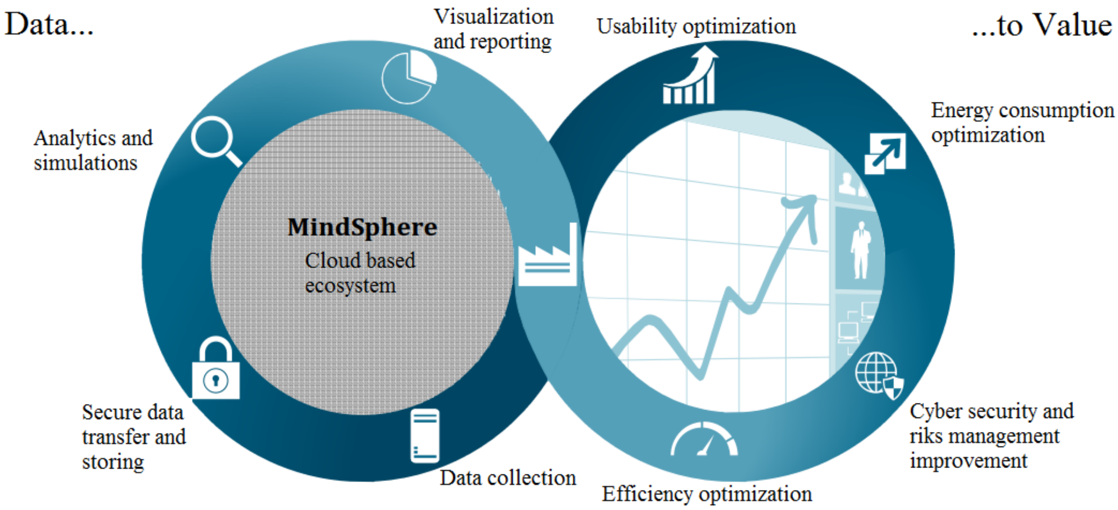

Figure 2.3 *MindSphere strives to create value through optimization by utilizing analyzed and visualized data. (Veijola 2016)*

Data ownership is a question that arises quite often when data is gathered from production equipment. Data gathered to MindSphere is owned by the customer, and the customer can decide who can access the data and to what purposes it is used. (Naujoks 2016)

In general, a modern IoT platform consists of eight different areas or components (Scully, 2016. See also figure 2.4 below):

1. Connectivity & normalization: Ensures object connectivity and harmonized data formats by bringing different protocols and data formats into one “software”, thus ensuring accurate interaction with all devices.
2. Device management: A backend tool for the management of device status, remote deployment and updates. Ensures that connected devices are working properly and updates software in the devices.
3. Database: Scalable storage of device data.
4. Processing & action management: Rule-based event-action-triggers which enable actions based on collected data.
5. Analytics: Complex analysis of basic data and predictive analysis, which brings the most of the IoT data value.
6. Visualization: Dashboards of data, which allow humans to see and analyze patterns from data. For example, line-, stacked-, or pie charts, 2D- or even 3D-models.
7. Additional tools: Allow developers to test and market IoT applications by visualizing, managing and controlling connected devices.
8. External interfaces: Connect 3rd-party systems and wider IT-ecosystems (ERP, CRM) through API (application programming interfaces), SDK (software development kits) and gateways.

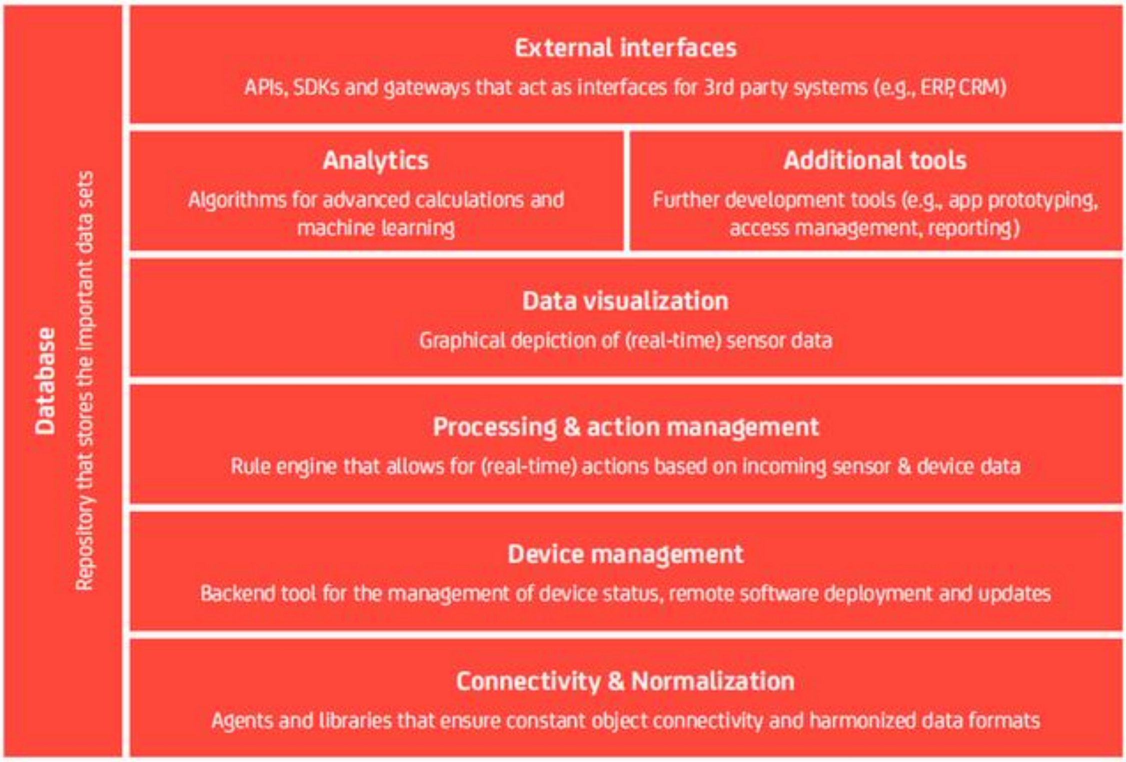

Figure 2.4 *The eight components of a modern IoT platform. (Scully 2016)*

Since an IoT platform essentially connects several different components over public internet, security becomes a very important issue. The threat of cyber-attacks can be minimized, for example, by using built-in security design. (Scully 2016) Data security is discussed more widely in chapter 2.4.

2.3 Benefits and possibilities of remote monitoring

Remote monitoring can provide several benefits and possibilities to all stakeholders involved: Customer, Sales and Marketing, Support and Service, and R&D. Stakeholders can have a clear view of equipment usage and events. Since maintenance can be planned optimally according to the actual usage of equipment, maintenance costs can be reduced and efficiency can be increased. This creates, for example, new service business opportunities. Optimally planned maintenance also means that unexpected machine failures can be reduced and dangerous situations due to malfunctioning can be avoided, which leads to increased safety. Other benefits of utilizing remote monitoring data may include increased machine performance in the next development cycle, decrease of warranty costs, reduced downtime, cheaper insurances and increased employee satisfaction (Elo 2016). Decrease of warranty costs is linked to fewer reparations during warranty time and cheaper insurances may sometimes be offered by insurance companies if it is possible to predict needs for machinery repairs before machines actually break. Figure 2.5 below illustrates vision of service business development.

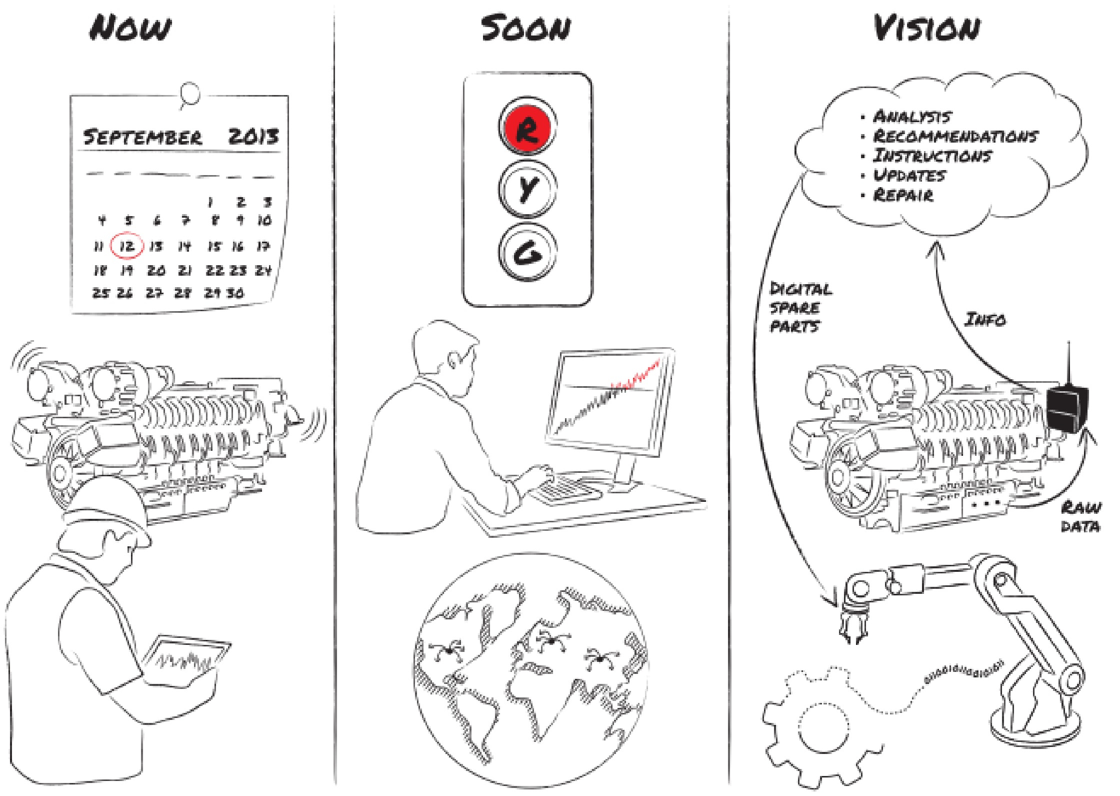

Figure 2.5 *Service business development will open new opportunities, such as condition-based maintenance. (Jurvansuu, Ailisto et al. 2013)*

By utilizing new data compression techniques, users of remote monitoring tools are able to view user-friendly overviews and track changes in massive data streams instead of tracking every piece of data all of the time. However, users are still able to drill down to the real issue and see what is causing the errors in the machine. In the future, service engineers can just ask what could cause irregularity in a particular machine, and historical data of the machine in question can be explored and a probable reason given in seconds. (Evans, Annunziata 2012)

Monitoring data can be utilized in several different areas. IEC 60300-3-2 standard (2004) lists the following common machine data utilizing targets (Kunttu, Kiiveri 2012):

- Maintenance planning
- Modification allocation
- Spare part and resource need estimation
- Definition of reliability requirements
- Feedback for design

Practically these utilizing targets are all different decision making situations, which all can be supported by utilizing collected relevant data on every organization layer. In general, the information provided by remote monitoring can significantly help stakeholders to make better decisions related to production machines and the process itself. (Kunttu, Kiiveri 2012)

2.3.1 Decision making

In any organization, decision making can be divided into three layers: strategical, tactical and operational. (Tölli 2012) Remote monitoring data can be utilized on all of those layers.

Strategical decision making is related on long term planning inside an organization. Strategical decisions contribute, for example, in business development, which requires understanding of the whole business area. The main purpose of strategical decision making is to decide on an organizational action plan and to create a strategy to execute the action plan. Strategical decisions have an influence on the whole organization or at least the most of it. Strategical decisions are made on the high level of organization hierarchy and they are usually unique. (Tölli 2012) Based on the remote monitoring data the manufacturer knows better what the customer needs and in which direction the market is going. With this information they can make better strategical decisions related to any development work.

Tactical decision making is related to mid-term planning. On this level decisions are made related to budget, resource allocation and operation practices. Tactical level is responsible for operational level’s resource adequacy, which means that the operational level has enough money, human resources, and so on to execute the tasks they should do. Tactical plans are developed, for example, in the areas of production, marketing, personnel, finance and plant facilities. (Tölli 2012) On this level remote monitoring data can be used, for example, as feedback for machine designers: if a part used on the machines breaks too easily, it should be changed on the next design cycle.

Operative decision making means that decisions are made on short term planning and on a daily basis. Practically, the operative level is responsible for the efficient use of allocated resources. Operative decision making is restricted in some part of the organization and is focusing on internal matters. Operational level includes, for example, everyday maintenance and usage of production equipment. On this level decisions are often made by routine and according to the habits. Normally operational decisions are made on lower levels of the organization. (Tölli 2012) On the operative level remote monitoring data can be utilized, for example, to optimize machine utilization efficiency on a daily basis and to optimize maintenance intervals of the machines.

2.3.2 Customer

Speed and reliability are critical factors for container transport companies. They strive for meeting customer needs by delivering high quality for low costs, which naturally is not an easy task. The time the container ship spends in the terminal must be minimized and therefore containers must be moved from ship to terminal in a fast and reliable way. The operations inside the terminal must also be efficient and reliable in order to be able to service the trucks which are transporting the containers on land. (Nijkamp, Wiegmans et al. 2004)

Reliability is often considered as the most important quality aspect in container terminal transport services, especially in Europe. Furthermore, it is important to minimize the number of damaged or lost containers. These both aspects set high requirements for the container handling machinery. (Nijkamp, Wiegmans et al. 2004)

Capacity management in container terminals is highly important, due to the transitory character of provided services, which means that the terminal operator cannot make any stocks. Many terminals monitor the time that a truck spends at the terminal. The target is to service a truck within 30 minutes of arrival. Due to strict contracts, all of the risks related to delays are passed to the terminal operator. This means that the capacity has to be utilized well. Ideally, capacity management results in a minimally unused capacity. (Nijkamp, Wiegmans et al. 2004)

Remote monitoring can offer the customer better equipment usage information as well as benefits related to safety, maintenance and costs. For example, overloads, emergency stops and other safety issues could be monitored and clearly brought to the customer’s attention for possible corrective actions, which could include, for instance, operator training to improve worksite safety. With remote monitoring it would be possible to optimize the need of maintenance by analyzing real equipment usage data in real time and so perform maintenance at the optimal time. Therefore, unnecessary time-based maintenance could be avoided, or if the equipment is heavily used it could be maintained before the break-down. Either way, customer would save money by avoiding unnecessary service work or by avoiding costly production down time. (Automation.com 2014)

Real time remote monitoring at the fleet level makes it possible to eliminate waste in fleet scheduling. By utilizing movement planning software, operators can observe how the equipment fleet is working and moving, which provides the possibility to control the fleet in an optimal manner so that every machine is working efficiently. (Evans, Annunziata 2012) In a container terminal the position of machines is tracked with a navigation system by utilizing technologies such as GPS (Global Positioning Systems), automatic magnetic measurement system or RFID (Radio Frequency IDentification).

Remote monitoring can offer real data from the customer’s own operation as KPI (Key Performance Indicator) values, which can be utilized to make the terminal more efficient. Basically, KPIs are selected variables that the terminal operator can use to assess, analyze and track container handling processes. The most common KPI’s are listed below (Red Lion 2015):

- Count: Tells the amount of produced products. In the context of container terminals this could mean, for example, the number of moved containers. Often refers to the number of containers moved since the last shift or machine changeover. Many companies compare individual workers to create a competitive environment among workers.
- Rate: Machines produce products at variable rates. Faster rates may result in a dropped quality and slower rates may result in lower profits. It is therefore important that operating rates remain consistent.
- Target: Many companies display output, rate and quality target values to motivate the employees to meet the performance targets.
- Takt time: Time to complete a specific task, or cycle time. Typically relates to the cycle time of some specific operation, but can also indicate how long it takes to produce a product. Manufacturer can determine possible bottlenecks within the process by utilizing takt time.
- Overall equipment effectiveness (OEE = Uptime * Performance * Quality): Determines resource utilization. OEE is calculated by multiplying three different values: the machine uptime percent, the percent of maximum performance (i.e. how many containers maximum a crane can handle per hour?) and the quality percent (i.e. have any containers been damaged or lost?) Manufacturers want the OEE to be high because it indicates that machines and personnel are well utilized.
- Downtime: Downtime simply tells for how long a machine is not available for productive work. Downtime can be caused, for example, by breakdowns or machine changeovers. When a machine is not operating, profit cannot be made, which is why downtime is one of the most important KPI values for the manufacturer. Manufacturers typically require that a reason for the downtime is recorded, so that they can view the most common reasons later on.

2.3.3 Sales and Marketing

Industrial IoT and remote monitoring can increase business and sales in many ways. When a business has access to real time data and the data is fully utilized, the benefits of Industrial IoT can significantly increase sales and make target marketing easier. (Larson 2015)

Industrial IoT creates great amounts of data, which is collected through different smart devices. This data is often called *Big Data*. In order take advantage of collected Big Data, B2B companies need to use personalization, like B2C companies do. The data can be used to target potential buyers and to customize sales pitches according to previous preferences of the customers. This strategy is not only to make the customer feel special with personalized offers, but it can also be used for more efficient planning and increasing conversion rates. (Larson 2015)

Immediate real time information reported from smart devices is an effective way to get information from customers. This data can be used for upsells, reorders and so on. When customers see and experience that the manufacturer is paying attention to them, they are more likely to be willing to continue business with the manufacturer in the future. (Larson 2015) Timing is a key element in B2B sales situations, as engaging potential customers at the right time often causes problems for sales and marketing personnel. With Industrial IoT, timing is easier, because there are ongoing dialogues with the customer all the time through the data. There is no need for holding focus groups or sending out surveys and waiting for the results. (Cernel 2015)

Product usage data was previously only available through customer surveys and other time-consuming data collection, but with Industrial IoT the data can be accessed quickly and efficiently. Information, such as how customers use the product, when they use the product, and how often they use it, allows the manufacturer to make better estimations of their own offering and how the offering should be improved to enhance business opportunities. The manufacturer is able to adapt the product to better suit the customer's preferences and to accommodate future customers, providing better products in the end. (Cernel 2015)

Industrial IoT can offer an effective way of documenting and managing the customer experience for a company. The amount of data Industrial IoT provides can make the picture of the customer and their preferences clearer, and the manufacturer can so offer meaningful and relevant industry insights to the customer, which can create more sales in the long run. (Cernel 2015)

2.3.4 Support and Service

Maintained systems are becoming more complicated, which means that more technology is needed to fulfil the constantly tightening requirements for quality, energy consumption, and emissions. For technical or economic reasons, users are not able to maintain the systems by themselves. This is leading to a situation where manufacturers have a great opportunity to create new business through service. Manufacturers have knowledge and the ability to maintain a product more efficiently, allowing the customers to focus on their core business. (Jurvansuu, Ailisto et al. 2013) However, a key question that often arises is: "What is the value of the services for the customer?" (Hemilä 2015)

The manufacturer should offer services that support end the customers' business needs, in addition to just producing sophisticated products more efficiently. These services should be tightly integrated with the product, which is essential for the manufacturer's competitiveness and the ability to obtain loyal customers in the market. The services could include, for instance, maximizing the operational uptime of machinery through appropriate maintenance strategies like the condition-based maintenance (CBM), on-demand production, the supply and assembly of spare parts, and optimizing process capacity and quality by controlling and tuning the process and the environment based on monitored real time information. A typical example of the management of distributed machinery is fleet management, which means global online monitoring of the usage rate and condition of a machine. (Jurvansuu, Ailisto et al. 2013)

In the future, services that bring added value to products are forming the market (Jurvansuu, Ailisto et al. 2013). The service business is based on the main service offerings that traditionally have been delivery, install, maintenance, modernization and full replacement. These services will exist in the future as well, but their content may be changed through digitalization and Industrial IoT.

Manufacturers that can provide the most interesting and valuable services to accompany their products will be the winners in this competition. Updating and maintaining products must therefore be made as easy as possible for the customers, who need to focus on their core business and whose knowledge of the product may be limited. (Jurvansuu, Ailisto et al. 2013) Figure 2.6 below illustrates a vision of how the machine service work could be done in the future.

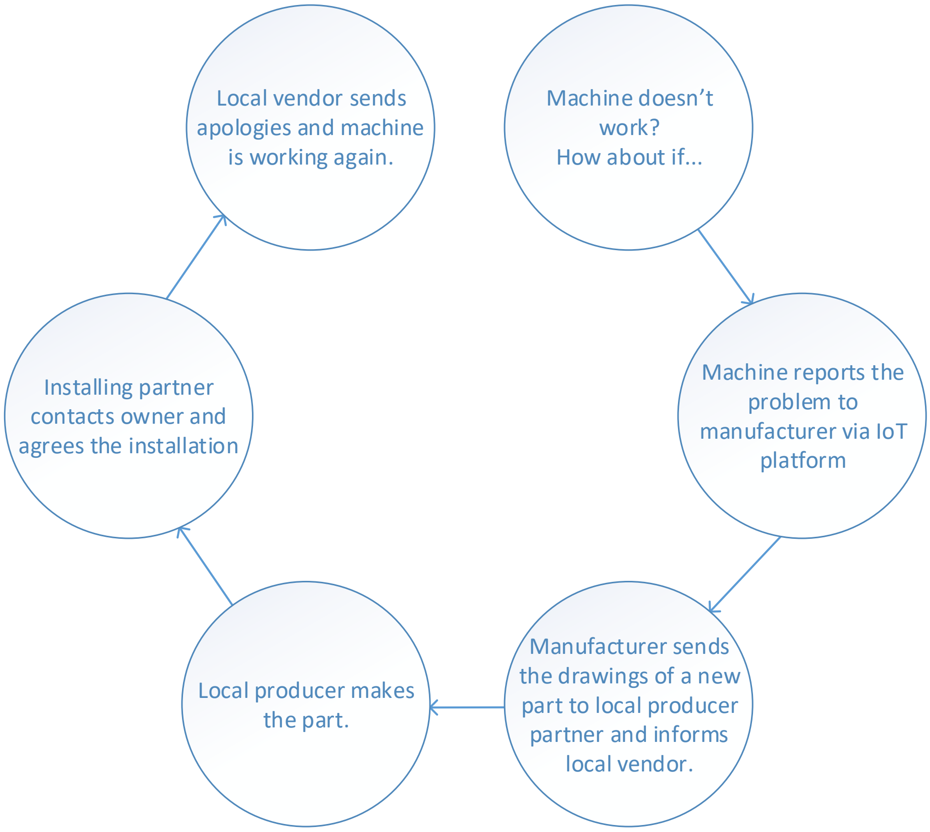

Figure 2.6 *Vision of a service loop. (Adapted from Jurvansuu, Ailisto et al. 2013)*

Industrial IoT will be increasingly utilized in asset management, for example, by using a one dedicated office to monitor the entire equipment fleet's condition around the world remotely. The service ecosystem of partners will be utilized to perform maintenance work. (Jurvansuu, Ailisto et al. 2013) Figure 2.7 illustrates how the service ecosystem relies on technology to enable new service business.

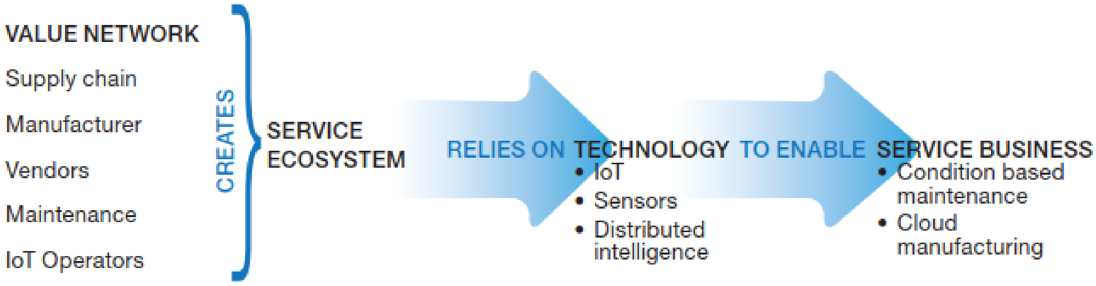

Figure 2.7 *Service ecosystem relies on technology to enable new service business.(Jurvansuu, Ailisto et al. 2013)*

In principle, the management and utilization of the right information is the key to successful service business. Devices can produce a lot of information, but humans can also provide valuable information about the machines. People who are working and doing the service work can provide right and updated information about the configuration and changes made on the machine. After the initial commissioning, machine configurations and electrical changes are often made, so it is important to have up to date understanding of the installed machine fleet to provide better service for the customer. (Jaakkonen, Kääriäinen et al. 2016)

Cloudfield Operations' QFL (Quick Field Logistics) strives to offer a solution for collecting data from the people who are working on the field. The goal for the QFL is to keep the machines' drawings, ongoing issues, service history etc. up to date, which makes it possible to provide more effective service for customers and to save money for service providers. The data that the QFL is collecting is in many cases impossible to gather only with sensors or other technical solutions, which is why it also requires actions from a human. For example, sensors cannot measure whether electrical wirings and drawings have been changed, so it is required that employees keep the drawings up to date. QFL makes it easier to keep up to date information available for all employees. Figure 2.8 below shows a mobile user interface of the QFL application.

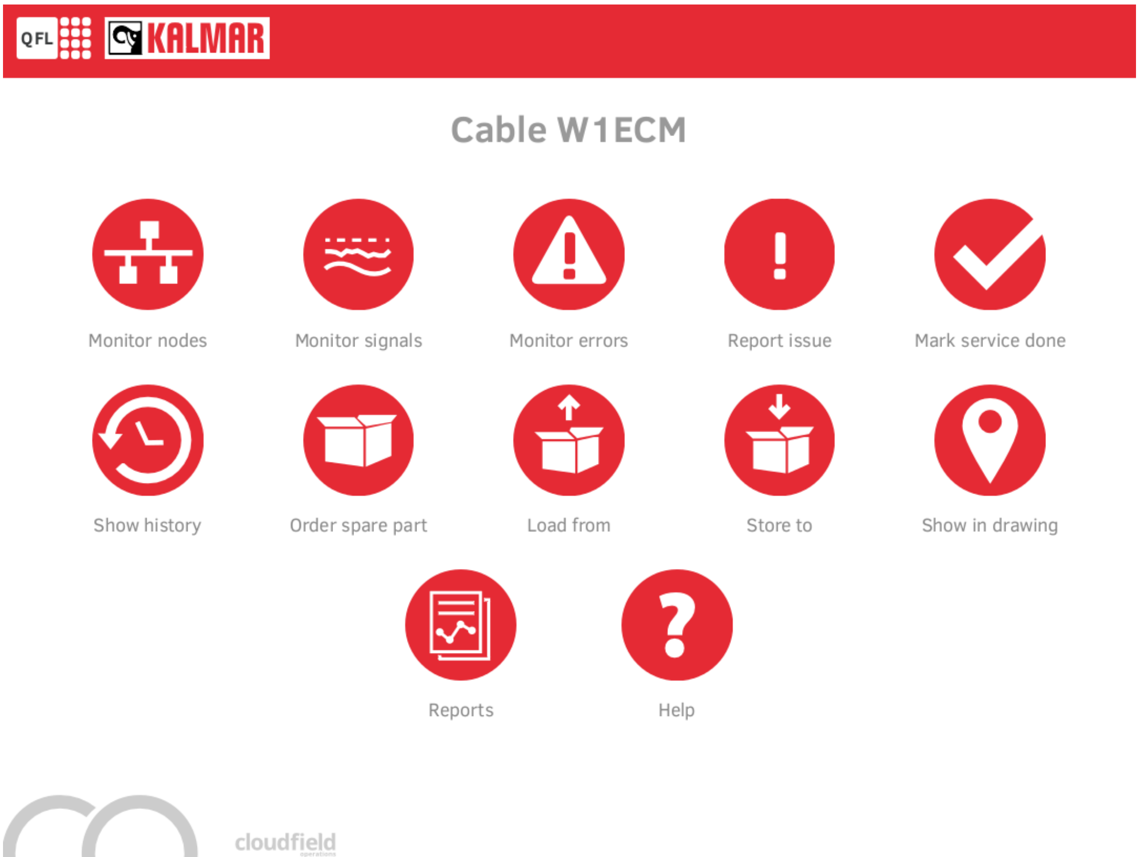

Figure 2.8 *Screenshot of the QFL web application; service workers can, for example, report issues, order spare parts and view electrical drawings through the application.*

QFL is used by reading unique RFID tags or QR codes (Quick Response Code), which are attached to machine parts such as bus cables, motors and switches. Tags are read with a mobile device, which automatically opens the corresponding web application view for the machine part. Service workers can, for example, report issues, order spare parts, view electrical drawings or monitor active issues and load configurations through the application. Figure 2.9 below shows the “Active issues” view of the application.

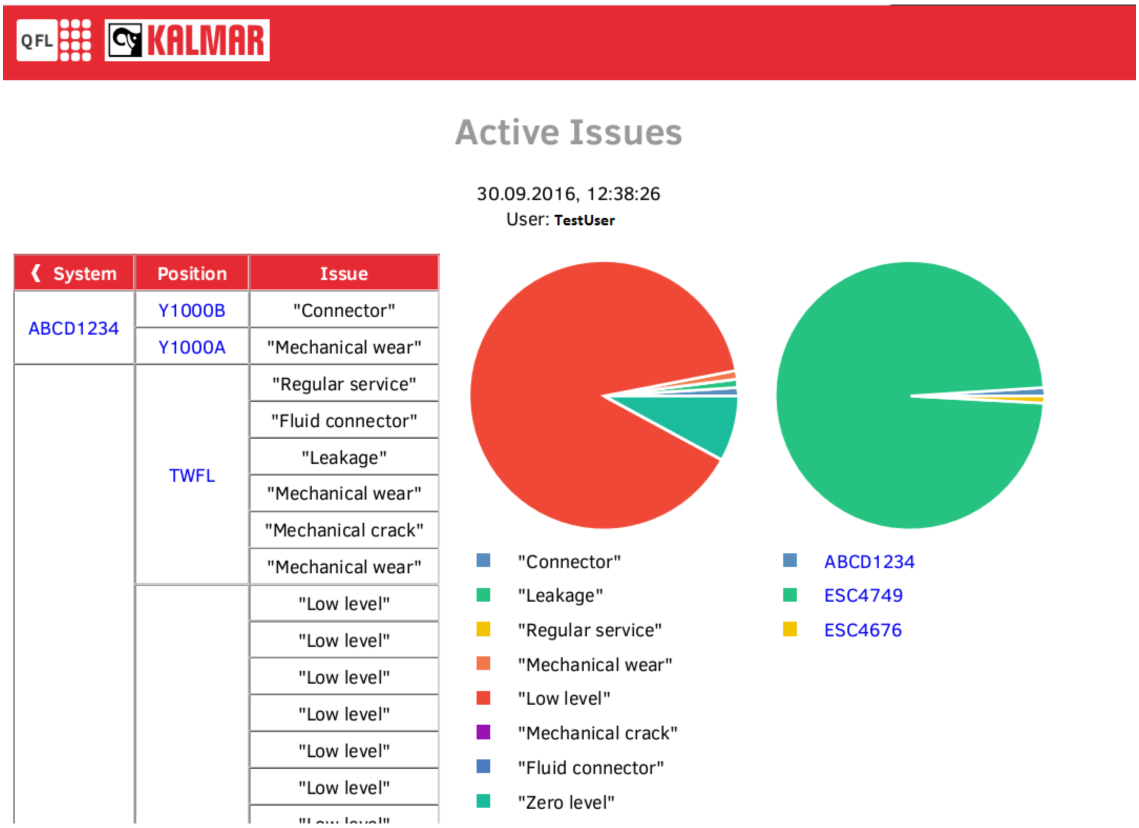

Figure 2.9 *Screenshot of QFL web application; active issues can be monitored through the web application.*

Instead of the earlier machine-centralized business, there will be more service business, which will partly replace the traditional business concepts. The traditional customer – service provider relationship will change when the added value for the customer is provided in cooperation with different service and technology providers. (Jaakkonen, Kääriäinen et al. 2016)

One of the biggest challenges in Industrial IoT is to adopt a new way of thinking and to recognize the new potential business areas in the company’s own business. It is easier for a company to make a decision of acquiring a new, expensive production machine than starting to rethink the operations from a new point of view and pondering if there are whole new services available for the customer or other stakeholders. (Jaakkonen, Kääriäinen et al. 2016)

2.3.5 R&D and Design

Machine designers usually have design instructions and knowledge, which are guiding the decisions during the design phase. Often the knowledge is empirical and not documented in any way. However, devices monitoring the condition and usage of a machine are collecting valuable information that designers could utilize, if the data were easily available. Analyzes and reports provided by monitoring systems are often designed to serve the customer and service personnel's needs, but not machine design and development. This is partly due to the fact that the customer owns the data, and only service personnel have the rights to utilize the data. If this automatically documented data were available for designers, recurring mistakes during the design phase could be avoided. (Franssila, Kunttu et al. 2012) Figure 2.10 below illustrates possible data sources that the designers and developers could utilize.

Figure 2.10 *Possible data sources for design and development. (Adapted from Franssila, Kunttu et al. 2012)*

The organization developing the products, often referred to as *Research and Development*, needs versatile reliability and usage information to be able to develop the right parts and areas in the machine. The data can be used to reach the optimal level of quality for the product. Naturally, the designed machine should always be good enough to fulfil the customer's needs. However, a product with a too high quality can be too expensive for the customer, and a low quality product can generate an unsatisfied customer. Reliability data from earlier products can, for example, reveal unreliable machine parts that should be changed in next design cycle. Subcontractors could also benefit from reliability information on their devices, their systems' life-cycle performance and the usage environment. (Franssila, Kunttu et al. 2012)

The most important goals in designing and developing a reliable product are to prevent faults or the possibility of a fault; to recognize faults that are inevitable and to find out the root causes for those faults; to define means to process occurring faults and to evaluate reliability of new products at design phase. (Franssila, Kunttu et al. 2012) Collecting data and remote monitoring can help on the first three goals. If the fault data is not collected and monitored, it is much more time consuming to recognize common faults and prevent those from happening.

Versatile fault data, especially from the warranty period, might be available in large quantities, but the challenge is to get the data in the right form to the right people in the organization. In a big organization the collected data might only be in the use of the collectors, and the remaining organization does not even know that the data exists. (Franssila, Kunttu et al. 2012)

Maintainability of a machine is another thing that the R&D organization can have effect on. Data collected from the service personnel working at the customer site can be valuable when developing machine maintainability. Well-designed maintainability can have an effect on predictive maintenance, since all maintenance work always causes downtime for the machine (Franssila, Kunttu et al. 2012). If the machine is easily maintainable, downtime can be reduced.

Data gathered from the equipment can be divided into four different classes (Kunttu, Kiiveri 2012):

1. Assembly information includes the unit’s and the system’s identification data, like component manufacturers, production lots and the commissioning date. According to the assembly information, event data can be allocated right and it also makes it possible to recognize, for example, the most costly parts of a system.
2. Usage data is data that describes how equipment has been used and what actions have been executed. Usage data can be utilized to find out the cause of a failure. Usage data is also very useful feedback for the design phase, when creating requirement specification.
3. Environment data describes the object’s operating environment. Environment data offers information on the process, raw material and external circumstances, like heat and moisture. By gathering a wide database from many different environments, it is possible to make conclusions of failure probabilities in a certain environment. This makes it possible to select better and more suitable components for different applications.
4. Event data in an industrial context is typically information related to faults and maintenance. Event data includes event time and duration, what has happened, what resources were utilized, how it affected on the equipment and so on. Event data also includes the information on moving the equipment to another place and decommissioning.

The aforementioned classes could be utilized during machine development work. For example, assembly and event data could be used to recognize candidates for development targets, which could be, for example, the system parts that are causing the most of the dangerous situations or the costs. The target for developing the critical parts of the system is to remove the reasons of the criticality. The environment and usage data can be used to support the development work. (Kunttu, Kiiveri 2012)

2.4 Data security concerns

When machines are remotely monitored from the other side of the world, it means that they need to be somehow connected through unsecure internet. Naturally, this causes concerns about data security among customers and machine manufacturers.

One of the biggest data security threats related to the industrial field is a situation where, for example, an attacker breaks into a manufacturing network and stops the whole production process of the factory or an automated container terminal. Stopping the production or even a slight decrease in production quality causes great economical losses. Cyber-attacks are often used for money extortion and can in the worst case even endanger human lives. (Nortio 2016)

There are a few possible ways to implement information security for IoT-devices. Many device manufacturers prefer centralizing the security on the edge of the internal network into a firewall or other active device inside the network. However, manufactures of network infrastructures state that security can be added as a part of network management close to the equipment infrastructure. Simo Säynevirta from ABB suggests that in the IoT world security is fixed to data items by utilizing access right management. Janne Järvinen from F-Secure states that there is not only one good solution, but instead there needs to be several different layers of security involved in IoT. Access right management and effective firewalls alone are not enough. In the industrial field attacks are typically APT (Advanced Persistent Threat) –attacks, which means that the attacker is infiltrated inside the network and starts slowly collecting information before the attack. Järvinen believes in multi-level security, where the game is not lost when firewall is penetrated. (Nortio 2016)

It is a common practice to try and prevent new threats from spreading with versatile and effective traffic monitoring by recognizing deviations or harmful factors and blocking their access to the network. A traffic deviation or a harmful factor can be, for example, an exceptional amount of data or an unexpected request from a previously unknown source. The request can be perfectly legitimate, but when the location of the sender is abnormal, it needs to be investigated. A multi-level protection is not always needed, because even a basic level protection decreases the willingness of the attackers to intrude the system. Those who do even something to protect their system are less inviting targets than those who do nothing. (Nortio 2016)

Since Industrial IoT is a set of interconnected machines, a platform and a foundation for “real time” services, it contains a varying amount of important and sensitive data, which has to be transferred securely and reliably. A solid and carefully defined IT network architecture including secure VPN (Virtual Private Network) connections and a private APN (Access Point Name) is the key to a securely connected machine network. (Pihkala 2016) The production system needs to be restricted from the office network, which is connected to the public internet, because the production system often does not have authentication and old devices cannot be updated to be secure. Segmentation makes the network more manageable. There should be firewalls to restrict unnecessary communication between the segments. For example, Modbus traffic from an automation system rarely needs to be allowed to office network. (Nortio 2016)

Building a secure IoT system requires expertise in IT, information security and automation systems. Because of this transdisciplinary competence requirement, security in automation systems is often not considered well enough. Earlier it was not even taken in consideration because there was no connection to the public internet. Remote connections can make production processes more efficient and optimized, but in the worst case the connection is available for hostile parties. Compromises and conscious choices between optimization and security need to be done. (Nortio 2016)

Even the most effective technical protections are not enough, when a human is the weakest link in security. Training of the staff is still the best way to protect businesses against the threats of the IoT world. Every employee needs to understand the different security threats and to know how to react to them. (Nortio 2016)

Network segmentation and firewalls are the most effective technical ways to increase security. Information security has moved on to the gateway level where harmful traffic can be monitored and rejected. Transferring important data outside of the organization can be managed, for example, with DLP (Data Loss Prevention) –solutions where a firewall is recognizing and rejecting forbidden traffic. Even though knowledge of data security threats has increased, companies have not taken enough actions to prepare for the threats. (Nortio 2016)

3. DATA MONITOR USABILITY

This chapter discusses topics related to usability and user experience in general and also from point of view of monitoring data visualization. This chapter aims to answer the following questions: Why are usability and user experience important when it comes to remote monitoring? How should the data be presented in order for it to be easy to understand?

Web page usability principles are mostly applicable also to larger remote monitoring screens. Therefore, some web page usability principles are also introduced in this chapter. Basic data visualization tools, such as different charts and their purposes, are also presented.

3.1 Monitor layout and elements

In this thesis I use the same principles to evaluate and to design layouts on web pages and larger screen displays, because the contents on both platforms are partly the same. A page layout is a visual presentation of a web page. The layout consists of several different elements like color, white space, horizontal and vertical scrolling, font size and color, and other design elements. The layout affects the ease of use and the quick identification of the page components, and therefore possibility to notice significant changes in data quickly. (Becker, Mottay 2001) Figure 3.1 below gives an illustration of the different aspects of a web page usability assessment.

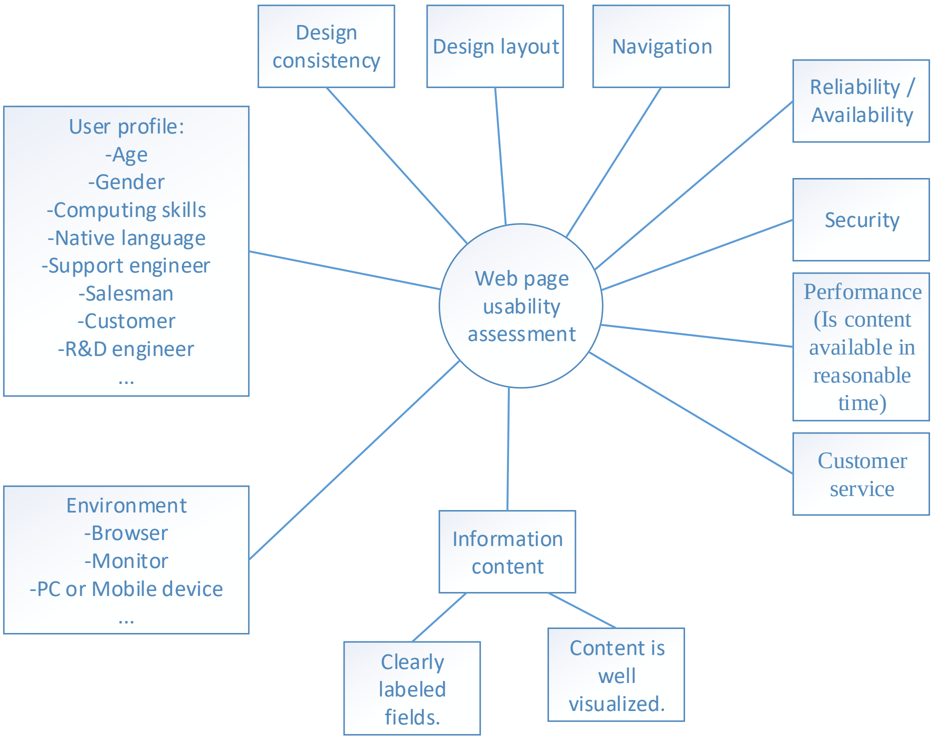

Figure 3.1 *Usability of data depends on several different factors. (Adapted from Becker, Mottay 2001)*

A web page layout should reflect the information according to its intended use. For example, time-based data could be presented on a sequential layout; topical data or information should be presented on categorical, hierarchical, or grid layouts. Page space should be delegated based on the importance of information, meaning that only data that matters is shown. (Somervell, Wahid et al. 2003)

If cyclic displays are used, it is important to be careful not to distract the viewer. Timings should be appropriate, so that the viewer has enough time to view all of the data. An indicator showing the cycle progress should also be used, for instance, a progress bar of some kind or a “1 of 5” type of indicator. (Somervell, Wahid et al. 2003)

Design consistency is one of the key elements when creating the layout for a usable web page. It means that the page components are in consistent locations within and across the pages. Components that require consistency include, for example, textual descriptions, labels, prompts and messages. Consistency of colors is required for links, background and text, among others. Design consistency makes pages easier and more efficient to use, because all pages have a common look and feel. (Becker, Mottay 2001)

When designing a layout, cultural differences need to be taken in consideration, because they can have an influence on things like the use of graphics, textual organization or the choice of colors. In some cases, the use of a particular color as a background or as indicator for an error messages may be inappropriate or misleading. A color might have different meanings in different countries, for instance, red color may mean a warning or an error in the US, but in Asia this might not be the case. For example in China, red is traditionally seen as color of good luck and happiness. Other aspects that need to be taken in consideration in layout design are timely and correct error messages, prompts, button labels, textual descriptions, help and customer service information (Becker, Mottay 2001).

3.2 Data visualization

When designing a data monitor, information content is crucial. Presenting and analyzing the data is the core of data monitoring. It should be clear why the data is analyzed when presenting and visualizing data. Rugaber (2015) states that creating nice visualizations and dashboards for the masses is not the purpose of data analysis. Data analysis is more than just tracking performance, monitoring customer behavior and measuring effectiveness of processes (Rugaber 2015). The following paragraphs discuss how and why data should be visualized.

The first phase of visualizing data is defining to whom the data is visualized and who will be using the created dashboards. Then, it is necessary to create a wireframe that guides meaningful action in the organization by choosing the KPIs that are vital to answering strategic questions within the business. Next, thresholds for when data values fall outside of statistically normal values should be defined and a visualization that easily identifies where the abnormality is happening should be created. Finally, probably the most interesting question to ask is: What actions should our people take with this information? (Rugaber 2015)

In data visualization it is important that metrics are presented in comparison with a set of threshold values to make it easier to evaluate the numbers shown on the dashboard. For example, colors can be used to highlight the values that are outside the target value; red could present values below the target and green values above the target.

Visualizations should be kept simple and understandable in order to help the audience to understand high-level overview information quickly and to utilize the visualization effectively. (Rugaber 2015) The presence and an overview of information should be shown, but not the details. Details can be viewed on a detailed view. (Somervell, Wahid et al. 2003) Data values on graphs often need to be rounded and scaled to fit the whole graph on the screen. Another way to compress data is to show a statistic, like averages or subsets of the data. (Jerding, Stasko 1998) It is also important to choose the right visuals for the purpose. A few basic guidelines are listed below:

- Line charts are tracking changes or trends over time and show the relationship between two or more variables. (Rugaber 2015)
- Bar charts are used to compare quantities between different categories. (Rugaber 2015)

- Scatter plots are used to display values for two variables for a set of data. (Rugaber 2015)
- Bubble charts are used to display values for three variables for a set of data. (Rugaber 2015)
- Pie charts are used to compare parts of a whole. However, pie charts should be used carefully, because the pieces of a pie might be hard to compare. (Fenton 2009)

Even if visualizations and dashboards would be easy to understand, employees and customers may need to be encouraged to utilize the data. For example, metric-driven notifications and regularly scheduled email reports are an approach to get people to engage to the data. With these kinds of automated notifications users are alerted to examine their data values and take actions, if needed. (Rugaber 2015)

3.3 User experience

User experience (UX) means the user's entire experience of using a system, product or service and understanding the user's needs, abilities and what is valuable to the user. UX's best practices promote improving the quality of the user's interaction with a product and any related services. (usability.gov 2016) Positive UX is a central design target for interactive products and services.

According to Väänänen-Vainio-Mattila and Wäljas (2009) several heuristics can be defined for Web service UX:

1. Users should be able to add new service components. These components could be offered to them through the existing service. In some cases, users should even be able to create their own service components or applications.
2. Cross-platform service access: Users should be able to access relevant service elements on different devices like PCs, mobile phones and tablets.
3. Social interaction and navigation: Users should be able to interact with relevant user communities, and utilize other users' navigation histories in their interaction with the service.
4. Users should be able to notice easily if something changes in the service contents or in the user interface. For example, when using the service, users can easily find new content that is interesting to them.
5. The service should adapt to user's context of use and offer meaningful contextual information.
6. The service user interface needs to be usable and aesthetically pleasing, support user's trust and privacy, and other experiential aspects (Väänänen-Vainio-Mattila, Wäljas 2009). For example, web page reliability and performance issues can reduce user's feel of usability and trust. Performance is measured by the consumer waiting and system response times. Reliability is defined by how of-

ten the site crashes, the amount of downtime and error messages, and by the consistency of response times. (Becker, Mottay 2001)

These heuristics could also be applicable for remote data monitoring. For example, customers probably want to see efficiency and KPI data of the equipment fleet, whereas technical support experts might want to see more detailed technical data of the equipment. This means that the remote monitor service should be able to adapt to the specific situation where it is used. It is also important that the service can be accessed on different platforms since different stakeholders may want to view the data not only on the wall of the remote monitoring center but also on their PCs and mobile devices. Naturally, reliability and availability are also important, because people often avoid services that are not working with ease.

Remote monitor service users often cannot track all changes in the data all the time, which means that they want to have a way to see what has changed since the last time they viewed the data. One way to accommodate this would be to simply highlight the changed data, or to offer the user the possibility to add so-called triggers for the data, which means that if a limit value is exceeded, an alert is generated, for example, through email or SMS.

4. MAINTENANCE

The most common application for the remote monitoring data is improving machine maintenance and even predicting maintenance needs beforehand. Maintenance costs cause a significant part of the machine's whole costs during its lifecycle, and reducing these cost can offer a competitive edge. Predicting maintenance needs can also reduce machine downtime, which can be very valuable in critical applications, such as automated container terminals. The failure to maintain machinery can have severe consequences. Malfunctioning machines can cause safety hazards and unnecessary costs, as well as damage to people, environment, property and business.

The first part of this chapter (4.1) discusses what industrial maintenance means in general. In the latter part (4.2), a condition based maintenance approach is introduced.

4.1 Maintenance in general

Maintenance can be divided into four different types: corrective, preventive, predictive and proactive maintenance.

Corrective maintenance is the traditional way to maintain systems and equipment. Basic idea is to fix flaws and performance issues through system restoration - to make things "correct" again. Corrective maintenance can be divided into two types (de Faria Jr., Costa et al. 2015):

- Unplanned corrective maintenance: failure is corrected if it was not expected and it occurred suddenly.
- Planned corrective maintenance: fault occurs in a planned manner, for instance as a result of a run-to-failure maintenance plan.

In other words, planned corrective maintenance can be written into the production schedule, whereas unplanned corrective maintenance can happen anytime. The latter can be very costly.

Preventive maintenance aims to increase the reliability and availability of a system or equipment by avoiding the need for unplanned corrective maintenance. Thereby, the basic idea here is the prevention of failures by looking for corrections to faults before they occur. (de Faria Jr., Costa et al. 2015)

Predictive maintenance focuses on predicting equipment or system failures by following different parameters and equipment conditions systematically. This type of maintenance is not a replacement for corrective or preventive maintenance; it is rather an additional tool for minimizing maintenance costs and losses in equipment by monitoring specific parameters in the system. (de Faria Jr., Costa et al. 2015)

Proactive maintenance means maintenance with a focus on determining the root causes for equipment failure and completing required actions to prevent issues before they occur. The key in proactive maintenance is anticipation, since it commissions corrective actions aimed at the sources of failure. Proactive maintenance differs from other three maintenance types, because it focuses on more systemic elements of the maintenance program rather than monitoring the equipment itself. (de Faria Jr., Costa et al. 2015) For example, certain machines require that there cannot be any contaminants in lubricating fluids; by proactive maintenance methods we can ensure that the fluids are clean. If contaminants are detected through monitoring, lubricants can be replaced with clean fluids.

4.2 Condition based maintenance

Maintenance business has developed a lot during the past years; sensor technology enables us to continuously monitor systems and equipment conditions and to predict failures. Therefore, maintenance programs can now be optimized based on the information collected from the systems through the sensors. This relatively new approach to maintaining equipment is called condition based maintenance (CBM). (Peng, van Houtum 2016)

As a real world application we can imagine, for example, a boring process of mechanical parts. The production manager needs to specify the schedule of maintenance in order to guarantee that the boring machines are working properly. Additionally, the manager also needs to determine the size of the production lot. Traditionally, these two decisions are made separately to minimize different cost elements during the production. The maintenance schedule is normally done to minimize the cost of maintenance, downtime and failure, while the production lot size is determined to minimize, for example, inventory and the risk of lost sales. However, sudden failures during production can appear from time to time, and if they cannot be fixed immediately, lost sales may occur due to this period of downtime. (Peng, van Houtum 2016)

Condition based maintenance policies were created to determine optimal inspection intervals for weakening systems that are estimated from the monitored data, based on the stochastic degradation processes. In this context, a stochastic degradation process simply means that the system is not wearing or weakening in a predictable pattern. (Peng, van Houtum 2016)

5. CASE STUDY

The first sub-chapter (5.1) gives an introduction on automated container terminal and illustrates what kind of environment it is and what kinds of machines are used in the terminals. The purpose of the chapter is to give the reader better understanding of automated container terminals in general which in turn should help the reader to understand the rest of the case study. The first sub-chapter does not focus on any specific terminal.

During this thesis work, a demo version of a remote center was built at Kalmar’s Tampere Technology and Competence Center. The remote center itself and installed equipment are presented in chapter 5.2.

Chapter 5.3 discusses how remote monitoring data is collected and processed at Kalmar. The possible future utilization of a new wireless telecommunication technology called URLLC is explored, focusing on its possible benefits for remote services, such as monitoring, remote support and remote control of the cranes. Once the data has been collected, data for visualization needs to be selected, which is discussed in chapter 5.4.

An attempt to discover new possible data sources is also made. Chapter 5.5 discusses Kalmar’s future testing of LoRa based data transfer. This technology could, for example, make it possible to apply vibration analytics to cranes to create new kind of data which offers better prediction of crane maintenance needs. Another possible data source could be the Kalmar navigation system, which is also discussed in this chapter. The system is intended to make crane operator’s life easier inside a wide container terminal and also gather data from the operators.

The Kalmar Cloud is the place where the collected crane data is available for analysis. Chapter 5.6 introduces data visualization in the Kalmar Cloud and gives real examples of currently visualized customer’s equipment data.

The last sub-chapter (5.7) gives a vision for the future remote center. How remote center could be made more appealing to give customers better illustration of what the remote monitoring means and how they can benefit from it. The remote center as a room would basically be a working environment and show room for introducing Kalmar’s remote services for the customers.

5.1 Automated container terminal

Automation has been proven successful in the container handling business in recent years. There are multiple automated container terminals in the world, and even more terminals are being automated.

In a terminal, containers are stacked in rows called *blocks*. One block consists of one pair of rails and two ASCs (Automated Stacking Crane). The waterside end of a block services ships being unloaded and loaded, and the other side, called landside, services trucks and trains being loaded and unloaded. A block usually has eight rows of five containers high stacks with a narrow space between the rows. Rows of containers can be up to 400 meters long. (Blaiklock 2013) Figure 5.1 below shows one block with two ASC cranes.

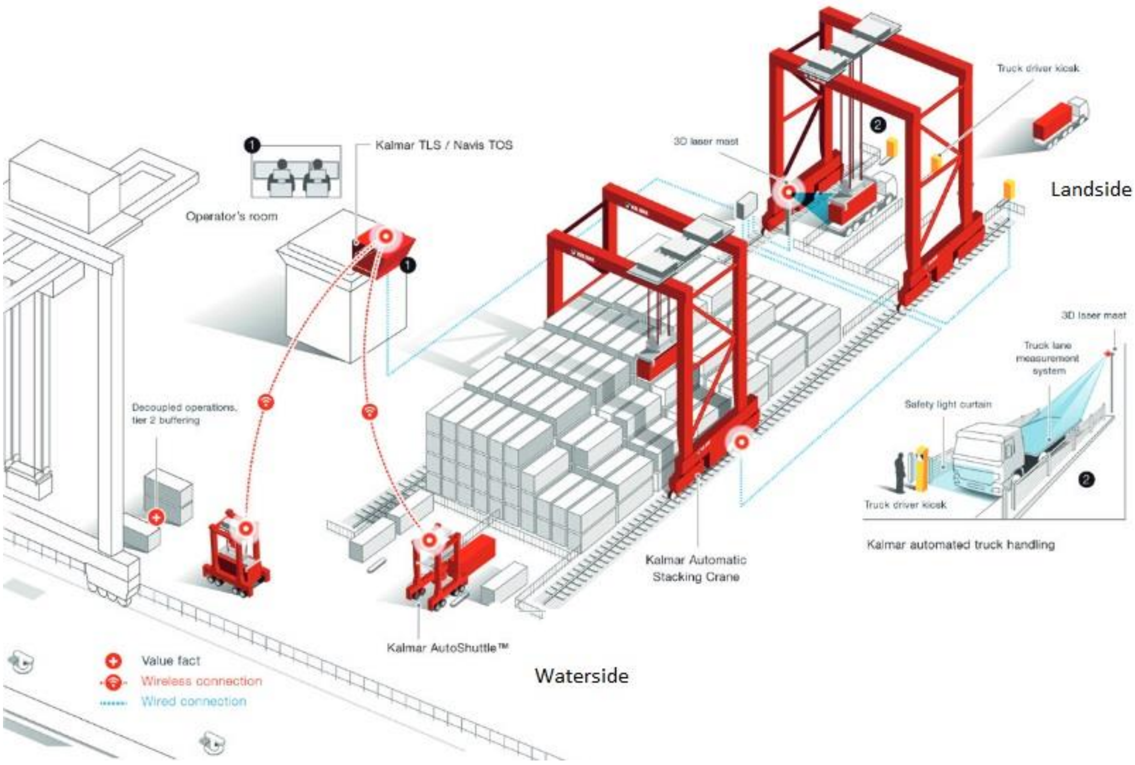

Figure 5.1 *ASC block consists of one pair of rails and two ASCs. (Kalmar 2016)*

An automated stacking crane is typically approximately 25 meters high and 35 meters wide. ASCs share one pair of rails and they are continuously stacking and unstacking the containers. The cranes are performing their work independently without any operators. The cranes are equipped with optical systems, which make it possible for them to recognize the containers. Scheduling software installed to a port management computer makes it possible to move right containers to the right place at the right time. An automated container terminal system provides a great improvement in productivity and reliability for a terminal. However, if something unexpected happens, there is a remote control room in the operations building, which allows manually driven operations. The remote control desk is equipped with video screens and a steering system, which enables, for example, loading a truck manually. (Blaiklock 2013)

ASCs are able to position containers with an accuracy of +/- 50 mm by using laser-based measurement systems. The cranes are mainly moving ISO-standardized 20, 40 and 45 feet long containers, which can weight up to 40 tons. The containers are being moved approximately at a speed of 5 meters per second. (Blaiklock 2013)

An ASC is powered by variable-frequency drives, which are controlling the crane's motors. The motors are used to provide the hoist, trolley and gantry movements. The drives, in turn, are controlled by a PLC (Programmable Logic Controller) over a local area network. The PLC receives the position data, compares it to the desired position and controls the drives to move the crane. (Blaiklock 2013)

Automation provides significant cost savings for terminal operators, since fully automated cranes are able to operate 24 hours a day. Additionally, damage to cranes or containers caused by the lack experience of the crane operator is reduced. Other human-caused errors are also reduced and safety is increased, since humans are not moving in the container handling area. (Blaiklock 2013)

Container terminals are generally quite wide areas with a large number of container handling machines. For example, the TraPac terminal at the Los Angeles port has 21 differently placed ASC stacks: 4 parallel, 15 perpendicular and 2 miniblocks. The TraPac terminal also has 28 automated straddle carriers moving containers from the STS cranes to the ASCs. (Kalmar 2016)

5.2 Remote center demo

The demo version of the remote center was built to Kalmar's Tampere Technology and Competence Center during the fall and winter of 2016. The remote center room is approximately 23 square meters (3,9 m x 5,9 m) in size and it has one single door and one double door. The wider double door makes it possible to introduce the room for a bigger group of people, such as customers. The room is furnished with four tables, one remote control desktop and four office chairs. Figure 5.2 below is a layout of the remote center room.

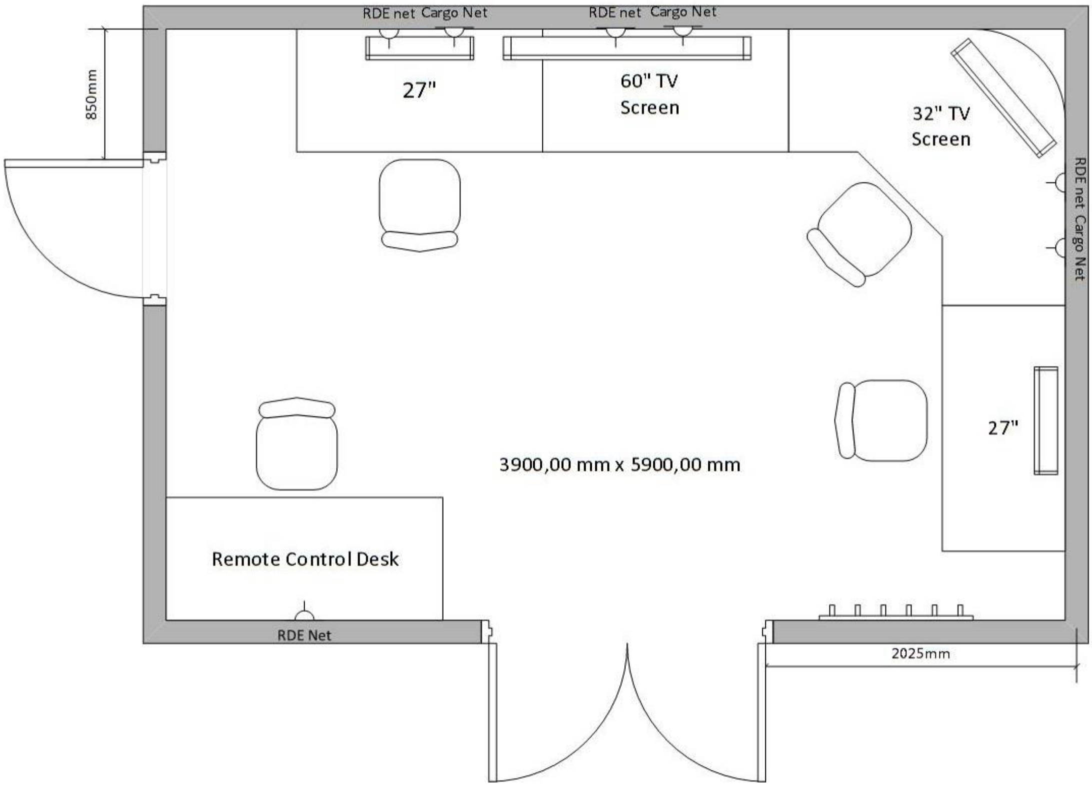

Figure 5.2 *Remote center room layout.*

Monitored data and video streams are visualized on four different screens. A large 60-inch TV screen is mounted on the wall opposite to the double door. This makes it easier to demonstrate the data for possible visitors. A smaller, 32-inch TV screen is placed on the corner table in the room; this screen is also used to visualize monitored data. Two 27-inch screens are placed on the furthest tables, and they are primarily used for work station purposes.

Two Lenovo ThinkCentre computers with keyboards and mice are placed on the same tables as the 27-inch screens. The computers have Microsoft Windows 7 operation systems and the regular Kalmar office tools installed. Both computers are connected to Kalmar’s office network and to Kalmar’s own RDE (Research, Development and Engineering) network through Ethernet sockets mounted on the wall. The computers are also connected to TV screens with HDMI cables, one to a 60-inch and the other to a 32-inch screen. Figure 5.3 below shows how the monitoring screens are actually placed in the room.

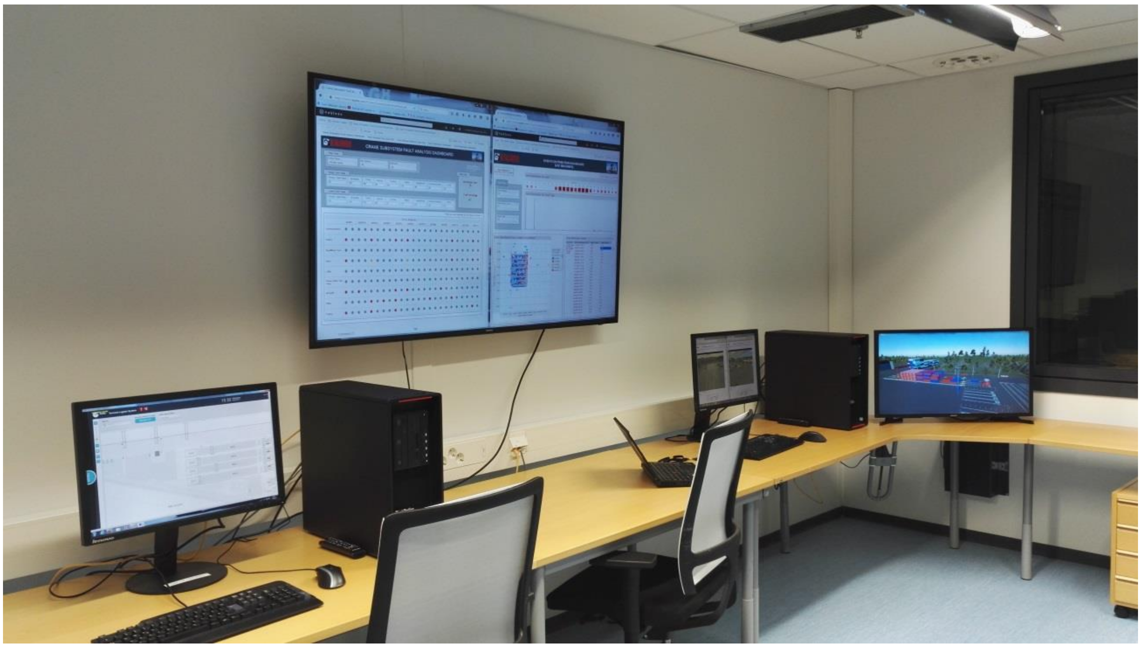

Figure 5.3 Larger screens are used to visualize data and live video streams. Smaller screens can be used as normal working stations.

This remote center is a demo version. In the future, there may be a possibility to move the remote center into bigger and more impressive facilities. The new facilities would be in another location at Kalmar's Tampere Technology and Competence Center.

Data collected to the Kalmar Cloud is visualized through a normal web browser. The browser visualizing the data can be extended to a larger screen, even when the computer is still being used normally.

Work stations can be used to establish remote connections to container terminals, such as the TraPac terminal at the Los Angeles port. Through a remote connection it is possible to monitor what is happening in the terminal in real time by utilizing video streams or Fleetview. Fleetview is a fleet management system that shows the positioning of container handling equipment in real time in a map form. Figure 5.4 below shows screenshots from Fleetview.

Figure 5.4 *Screenshots from Fleetview. Fleetview shows the positioning of container handling equipment and active alarms in real time, and allows controlling the machines individually.*

Fleetview allows control room staff to control each machine individually, which means that terminal operators can manually assign container handling tasks for the machines, if needed.

5.3 Data acquisition and future network infrastructure

Collecting data requires carefully designed and reliable data acquisition and storing infrastructure. This chapter discusses how data acquisition and storing is carried out at Kalmar. Future URLLC based wireless data transfer technologies are also introduced.

5.3.1 Data acquisition

Data is collected from container handling equipment in batches through a gateway device. Online logging data is stored in a TDMS (Technical Data Management Streaming) file format due to performance issues: the TDMS format enables processing considerable amounts of data. Online logging data is data which is continuously changing, such as counter values, measurements and positioning data. FMDS (Fault Management and Diagnostics System) is used to store the alarms generated by the equipment, error and event logs, parameters and documents. The main task of the FMDS is to store error notifications of local systems, but it also has other functions such as KPI report data, central repository of error descriptions, user groups and permissions, software administration, parameter administration, document administration, maintenance information and version number administration for crane components. Figure 5.5 below illustrates how data acquisition is done at Kalmar.

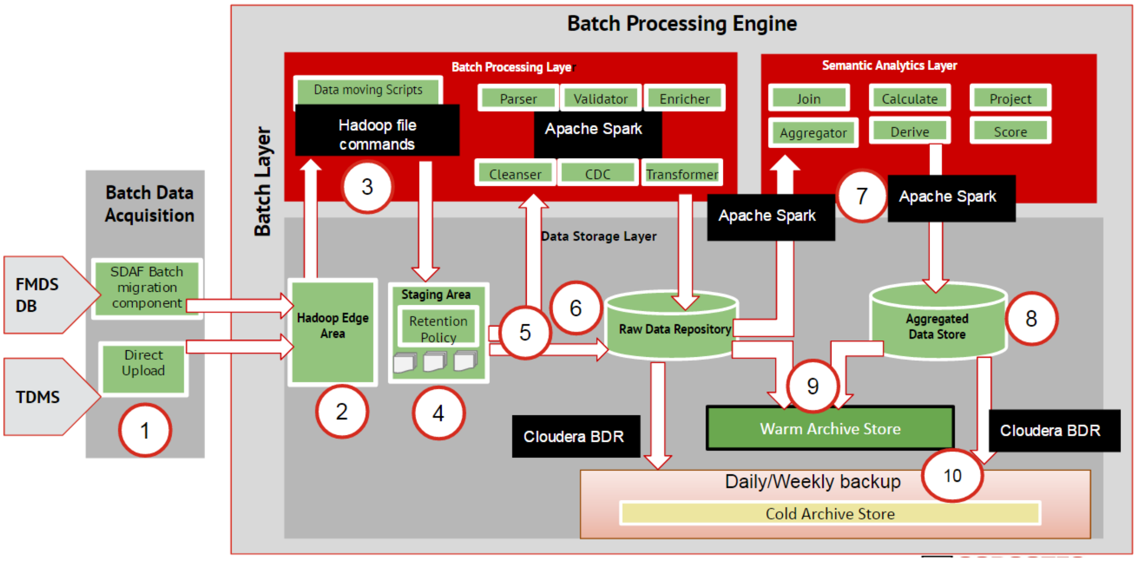

***Figure 5.5** Kalmar data acquisition and provision (Kouhia 2016)*

The TDMS formatted data and the data from the FMDS is moved into a batch processing engine through a Hadoop edge node (Hadoop Edge Area in figure 5.5), from which the data is moved through the batch processing layer to the staging area. The staging area is a temporary location, where the data is stored before moving it to the data warehouse (Raw Data Repository in figure 5.5). The data is stored in the staging area for timing reasons, because all new data has to be processed and available before it can be moved into the data warehouse.

The raw data repository is backed up by using Cloudera BDR (Backup and Disaster Recovery) daily and weekly. Raw data is moved to the semantics analytics layer, where it is analyzed and the data is mapped into familiar business terms. From the semantics analytics layer the data is moved to the aggregated data store, where the data is aggregated. The aggregates make it possible to make quicker queries for large data sets. The aggregated data store is also backed up daily and weekly. Data from the raw data repository and from the aggregated data store is moved to the warm archive store, if it is used frequently.

Figure 5.6 below illustrates how the delta file management is executed at Kalmar. The delta file management only allows processing a changed portion of a file, when the original file is completely backed up. The delta file management reduces the required bandwidth and unnecessary storage processing.

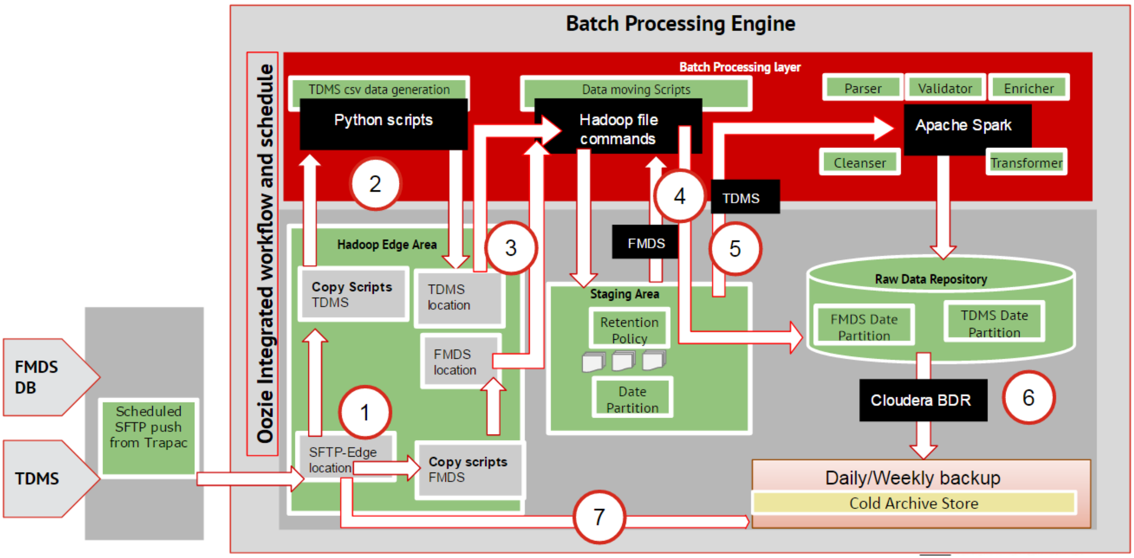

Figure 5.6 *Kalmar delta data management (Kouhia 2016)*

A scheduled SFTP (SSH File Transfer Protocol) file transfer moves the data to the Hadoop edge area, from which it is moved to the batch processing layer. From the batch processing layer the data is moved to the staging area, where the data is stored before it can be processed by an Apache spark at the batch processing layer. At this stage, the Apache spark can clean, parse, validate, enrich and transform the data. Finally, the data is moved to the raw data repository and backed up by the Cloudera BDR.

5.3.2 URLLC in automated container terminal

Wireless communication technologies are rarely used to remotely control the machines in container terminals due to difficult signal propagation environment and varying latencies. However, URLLC (Ultra-Reliable and Low-Latency Communication) is a wireless communication technology, which is designed for controlling machines and therefore promises low latencies reliably and deterministically.

Kalmar is already providing remote control for cranes in terminals by utilizing wired communication technologies, which can easily provide deterministic low latency control communication. In the future the cranes can also be controlled from a central control room located even in another country. If cranes could be controlled wirelessly, for example, installations and modifications in the terminal would be easier. Wireless connections would be especially important in RTG (Rubber Tired Gantry) cranes, because they are often used in terminals where infrastructural changes are not desired or not possible, since RTGs do not need rails like ASCs. If they could be made wireless, there would be even less need for new infrastructure, such as communication cables.

There is already the possibility of controlling some crane types with radio controllers. The radio controllers are essentially wireless, but they can only be used for service purposes, not actual container handling. The radio controllers are problematic since they use licensed frequency bands. Licensed bands cause additional costs and may not always even be available. URLLC-based technologies may provide a viable alternative for the radio controllers.

Kalmar is now starting to research and test whether the wireless communication in a terminal area could be done with URLLC technology. Figure 5.8 below illustrates how the URLLC communication for the cranes is built.

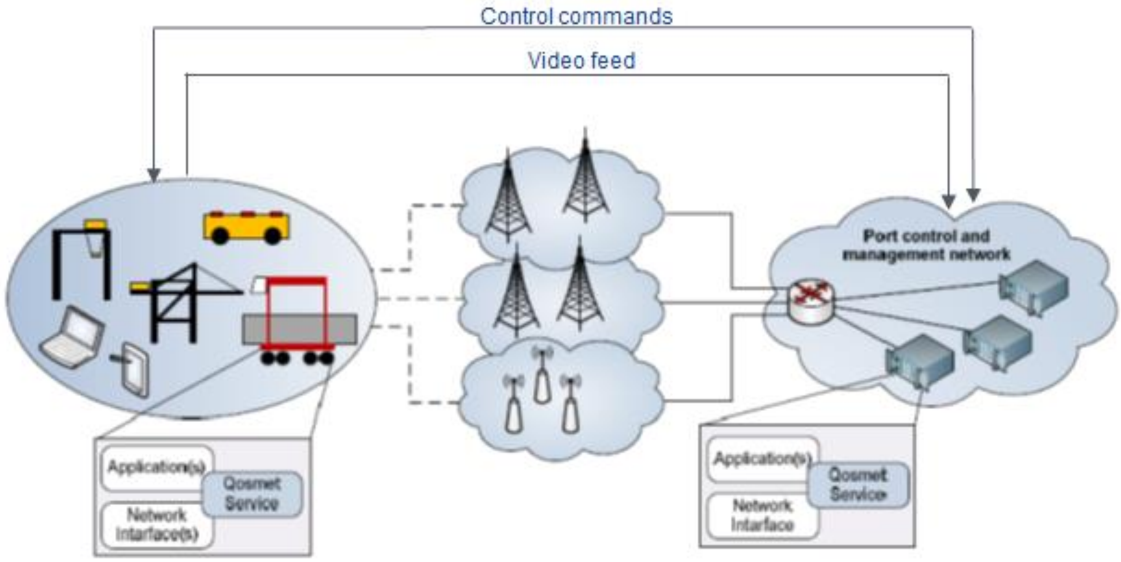

Figure 5.7 *URLLC communication in a container terminal. (Uusitalo, Yli-Paunu et al. 2016)*

An automated container terminal is a wide area and the URLLC signal should cover the whole area. Low latency and ultra-reliability is required throughout the area. As an example, a terminal can be approximately 3 km long and 0,5 km wide. However, in the research phase URLLC is tested at Kalmar's Tampere Technology and Competence Center on the test yard, which is only 0,4 km long and 0,2 km wide.

Access points are installed on 30 meter high light posts to ensure best possible signal propagation. It is important to carefully design the placement of access points to avoid blind spots of the network. For example, there might be problems on wireless communication with terminal tractors, which may be moving in relatively narrow spaces between container stacks. This means that a clear line of sight between the machine and the access point is not always possible. Obstacles, such as containers and other machines, can disturb and delay signal propagation. Weak signal propagation should not cause communication problems with higher cranes because a clear line of sight to the access point is more likely.

Even though communication has to be deterministic and latencies need to be very low, extremely low latencies are not required because humans are controlling the cranes. Since the human operator needs some reaction time anyway, a latency of approximately

200 milliseconds is satisfactory for video streams. Nevertheless, a very high reliability of control commands is required, as any communication error or timeout causes an emergency stop, which leads to a time-consuming process of bringing the machine back to operation. For example, the Profisafe safety communication timeout is 30 milliseconds. If the safety message is not successfully received during the 30 milliseconds, an emergency stop is automatically generated and the crane is fully stopped. In the worst case the lost safety communication can even break something, but in a typical case it just causes an emergency stop.

The level of communication reliability can be calculated by how many times the safety communication or the control communication is lost within a year, for example, with 50 cranes. Some communication breaks can be tolerated, as long as they are not long-lasting, meaning that a few data packets can be lost before emergency stops occur. The control PLC cycle time is approximately 10 milliseconds and if three packets are lost, it makes the cycle time approximately 30 milliseconds, which still can be tolerated.

The amount of transferred data depends quite a lot on the direction of the data. Downlink data usually consists of prioritized real time data, such as simple commands and control data, which means that amount of data is small. Currently the downlink data bandwidth for control data is 1 megabit per second, including TCP traffic, such as device status messages and diagnostic data. Typically, the downlink packet payload is less than 1 kilobyte. Much more uplink data could potentially be transferred, in which case the transferred data would mainly be non-time-critical video stream data or sensor data with time stamps and with a deterministic latency of a few hundred milliseconds. Currently, there may be up to 12 cameras streaming video simultaneously with only a bandwidth of 20 megabits per second per crane. With URLLC, a bigger bandwidth could be possible in order to achieve better video resolution.

5.4 Selecting the data for collection and visualization

One of the most important questions when collecting data is the following: What data should be collected and visualized? It does not make sense to collect every piece of data that can be pulled out of the machine. On the one hand, the amount of collected data would be enormous, and the data would very expensive to store and analyze. On the other hand, the data is collected because it is meant to be utilized somehow, so only the data that is beneficial should be collected.

It obviously depends on the point of view what data is beneficial and should therefore be collected and visualized. Different stakeholders have different needs. A customer is probably interested in the data that shows how the machines are operating, like fuel consumption and data related to effectiveness, such as the number of container moves and other KPIs. People who are accountable for the machine service are probably not interested in KPIs, but in more detailed information of how the machine has been working, such as motor temperatures and alarms, or faults the machine has been generating.

Kalmar has previously made a research related to collecting and visualizing data (Jokela 2005). During the research, three stakeholders were interviewed: a customer's terminal manager and service manager, and Kalmar's workshop manager. Interviewees were asked what data would be useful for them and what not. (Jokela 2005)

On the operative side the interviewed terminal manager found the following data to be interesting (Jokela 2005):

- Fuel consumption
- Number of container moves
- Operating hours and idling hours
- When machine has been operating
- Alarms
- Weight of the containers
- Not interested in who has been operating the machine

A service manager was also interviewed, which led to the conclusion that the service side benefits from the following data (Jokela 2005):

- Classification of alarms
    - By faults
    - By machines (which machine has generated the most of the alarms)
- Temperatures of motors and drives
- Service schedule (when machine needs to service)
- Fuel consumption average
- Not interested in the number of container moves

Kalmar's machine repair shop manager found the following data interesting and useful (Jokela 2005):

- Upcoming services
- Alarms
- Occasionally need for real time data
- Fault codes should match the codes in service manuals
- One should be able to wrap up alarms (the alarm list is hard to read if there are a lot of the same alarms)

All types of data previously mentioned can be seen as traditional data. It has been possible to collect this kind of traditional data for a long time with existing measurement technology. In the near future, for example, vibration data analysis can create new possibilities in monitoring machine condition. Vibration data analytics could be utilized, for example, to predict if a bearing is going to wear out or if a motor is in need of service. The next chapter introduces possible new data sources that could be utilized in Kalmar's business.

5.5 Data sources in future

Kalmar is currently testing new possibilities to provide more useful data from the machines in the future. This chapter introduces two of them. The first sub-chapter is about a LoRa-based sensor network and vibration analytics, which are going to be tested on the Kalmar's Tampere test field. The second sub-chapter introduces the Kalmar navigation tool, which is aiming to make the crane operators' life easier in the large container terminal, but also to collect crane usage and efficiency data.

5.5.1 LoRa & Vibration analytics

Low-cost machine-to-machine communication has traditionally been leaning on ZigBee, Wi-Fi and Bluetooth. However, in recent years LPWAN (Low-Power Wide-Area Network) technologies have been utilized more on the market. LPWAN is expected to close the gap between LAN (Local Area Network) and WAN (Wide Area Network) technologies, especially in the rising Industrial IoT market. (Downey 2015)

LoRa (Long Range) is one of the leading contenders on the LPWAN market. LoRa specifies how low-powered sensors and other modules can utilize sub-GHz frequencies to communicate through multiple gateways to a network server. LoRa network is analogous to the traditional cellular network, where end nodes are also communicating through gateway devices to centralized servers. (Downey 2015) However, unlike cellular networks, LoRa is designed only for low data rates ranging from 0.3 kilobits per second to 50 kilobits per second (LoRa Alliance 2015). Figure 5.9 below illustrates the LoRa network data flow.

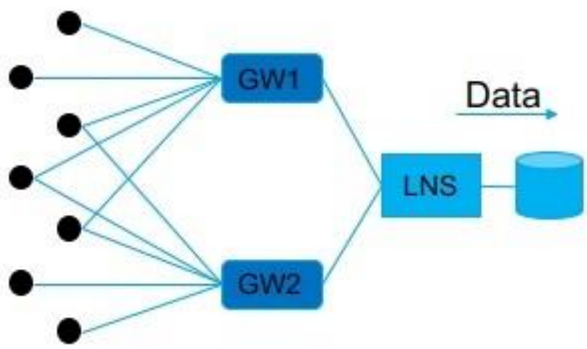

Figure 5.8 *Illustration of a LoRa network, where dots are end nodes, GWs are gateways and LNS is a LoRa Netowrk Server. (Ala-Paavola 2016)*

LoRa transceivers can communicate bidirectionally in the same ranges as traditional cellular network technologies, such as LTE, but with only 1/100th of the power consumption. Low power consumption makes LoRa suitable for battery-powered sensors and controllers, which are often used in Industrial IoT solutions. (Downey 2015)

A LoRa-based sensor network is being tested at Kalmar's Tampere Technology and Competence Center. LoRa transmitters with sensors are installed on test cranes and other test equipment. A LoRa gateway is installed on the roof top of Kalmar's office building next to the testing area.

The gateway used in the test has an IP67 enclosure, which means that it is water resistant. The gateway also has 3G or LTE mobile data capability and a programmable Linux platform. The LoRa transmitter has several interfaces, which enable attaching various external sensors. The transmitter has an integrated accelerometer, which can be used, for example, to see if the machine is moving. The transmitter is powered by a battery or an external power supply, it is programmable and it is IP67 certified. The gateway and the transmitter are presented in the figure 5.10 below.

Figure 5.9 *LoRa Gateway on the left and LoRa transmitter on the right. (Ala-Paavola 2016)*

The main purpose of the first test phase is to evaluate the performance of LoRa communication on radio frequencies. How far and under what conditions is the transmitter really able to send data and is the communication reliable? (Ala-Paavola 2016) Container terminals are challenging environments for wireless communications because machinery and stacks of containers create a narrow spaces and blind spots for the signal. However, as the data transmitted by LoRa is not time-critical, this is probably not a big issue, since machines and containers are moving in the terminal and will at some point be in a position where transmission can take place.

Three LoRa transmitters are going to be installed on the test cranes. The test cranes are being used for other tests at the same time as well, which means that cranes are used and moved around the test field quite often. (Ala-Paavola 2016) When cranes are used, data and test information on the crane movements can be collected. Transmitters send LoRa packets with a configured interval whenever the external power supply is switched on.

Two LoRa transmitters are going to be installed in cars, which are used for long range testing. (Ala-Paavola 2016) Test cranes can only be moved inside the test field, which is not far enough for long distance testing.

LoRa performance monitoring is implemented in an IBM Bluemix IoT environment, which provides a simple web-based user interface. The user interface visualizes key indicators with a history trend related to LoRa communication, such as received signal strength, packet loss and operational hours.

The purpose of the second testing phase is to analyze vibration data received from the test crane. The same sensor components as in the first phase are used, but the data is recorded with a higher accuracy instrument for further analytics. (Ala-Paavola 2016) The target is to create a profile classification based on vibration data. A possible classification could include the following statuses: not running, idling, light drive, heavy drive and so on. The final goal of the second phase is to have detailed usage data transmitted reliably through the LoRa network. Figure 5.11 below clarifies the second test phase.

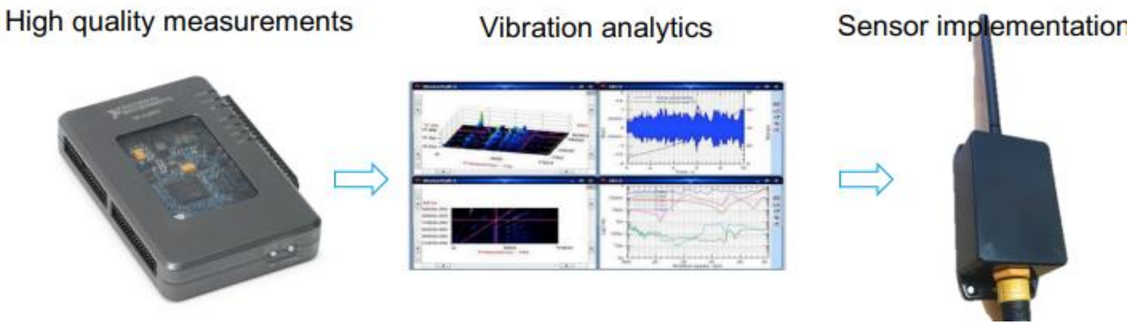

Figure 5.10 *The second phase of testing. (Ala-Paavola 2016)*

The LoRa-based Kalmar monitoring system is using a single gateway to cover a large container handling area, which means that network is relatively easy to build. However, it is possible to add multiple gateways to increase redundancy and to cover larger areas (Ala-Paavola 2016). The gateways send the collected data to the LoRa Network Server by utilizing regular cellular network technologies, such as 3G and LTE, which makes the gateways independent from the local network infrastructure in the terminal.

The LoRa sensors used in the test have several benefits: low unit cost, an integrated antenna, which means that they have no fragile parts, they can easily be retrofitted on existing machines and they involve no data communication costs. The sensors feature usage hour counting and reporting in near real time, as well as an integrated accelerometer, which can detect if engine is on or if the machine is moving. The sensors have a single power cable, which can be used to detect whether the machine electrics are powered on: if the sensor is powered, the machine is also powered, as the sensor is connected to the machine's electrics. The advanced sensor model also has an OBD (On-Board Diagnostics) –connector, which can be used to collect additional data, such as RPM (Revolutions Per Minute) measurement.

5.5.2 Kalmar Navigation system

Despite of container terminal automatization, there are still a lot of manually driven shuttle carriers. Large container terminals can be challenging especially for rookie drivers, because they do not have modern solutions in use for finding a container or a new place for the container. Another challenge in container terminals is safety; shuttle carriers are occasionally facing collision accidents or near-miss situations, especially in busy terminals. (Nortal 2016) At times, the most commonly used routes can even jam and the moving of containers can slow down.

Showing a target on a map and a navigation system can make the driving at the terminal easier. Seeing other shuttle carriers and dangerous areas on the map makes it possible to anticipate possibly problematic situations and increase the safety of the area.

Kalmar is aiming to develop an easy-to-use and extensible navigation application, which creates added value to the customer when they are using manually driven shuttle carriers. In the first phase, the application is used only by a test group of Kalmar's employees.

In the first phase, the Kalmar navigator –mobile application can only be used on Kalmar's own test field, and therefore the map and routes are only applicable for the test field. All possible routes are predefined, so that the application knows where, how long a distance and on what speed the shuttle carrier can move. Navigation to the target is done by utilizing Dijkstra's algorithm. Navigation application can be controlled through speech, for example, by saying: "Navigate to 4-A". (Nortal 2016) Below in figure 5.12 is an illustration of what the application could look like.

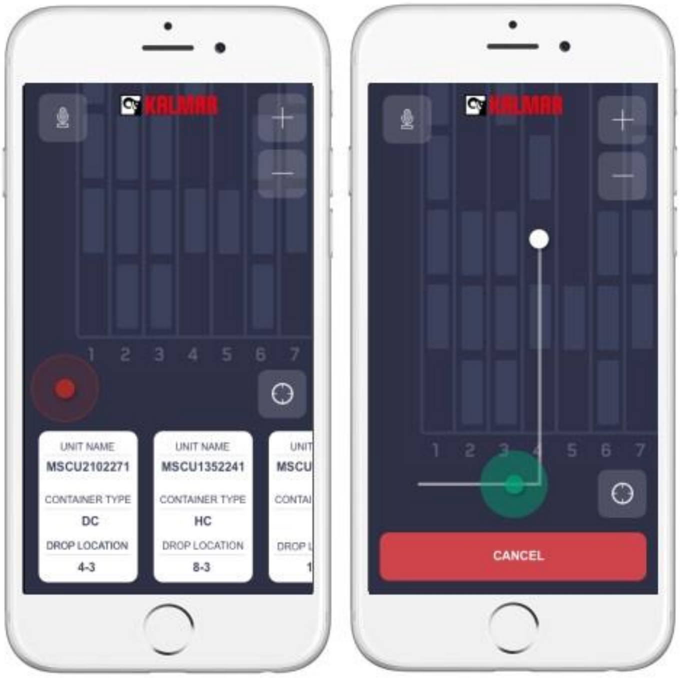

Figure 5.11 *Kalmar navigator –mobile application (Nortal 2016)*

In the second development phase, other shuttle carriers are also shown on the map, as well as the effect of congestion areas to the calculation of the shortest path (Nortal 2016). This makes it possible for the operator to choose a better path to the target, if necessary. Gamification of the navigation system is another development idea (Nortal 2016). Basically this would mean that the crane operator's working day is made more goal-oriented and even fun by showing how many containers he still needs to move before break.

Individual employees could be guided through the navigation application. At busier times, work could be divided so that the terminal area is better utilized. The application could also be used for real time monitoring and developing work efficiency. Safety can be increased by warning the crane operator of dangerous areas in the terminal through the application.

During the mobile user interface design, ease of use and simplicity is highlighted. The user experience of the application must be smooth and addictive.

5.6 Data visualization and analysis

Data visualization in Kalmar Cloud is currently made with commercial data visualization software Tableau. Tableau enables its users to connect, visualize and analyze data without actual programming experience.

An example case of data visualization from customer's equipment is shown below. In figure 5.13, data from Straddle Carrier is visualized in two ways: as a heat map and as a bar diagram. The “Event Distribution Per Hour” -chart uses a heat map which indicates when the most of the events or faults are happening. The bigger and darker the heat indicator is, the more events there have been. In the figure below, most of the events have happened at 15:00 – 16:00. The “Event Distribution Per Event Type” –chart uses a bar diagram which specifies what has happened and how many times during the day. In the figure below, a communication failure with the PLC has occurred three times.

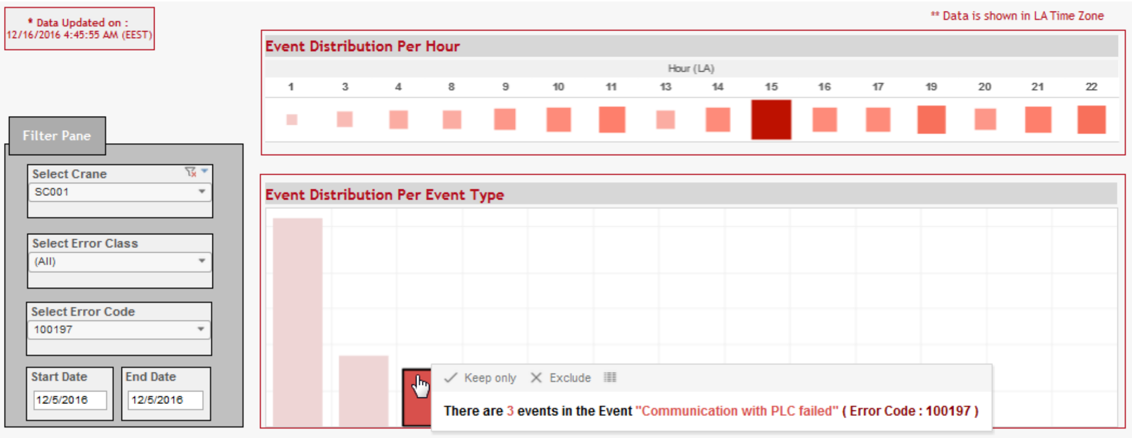

Figure 5.12 *Heat map shows when the most of the event are happening and bar diagram specifies what has happened and how many times.*

The “Event Distribution Over Location Co-ordinates” –chart utilizes location information to define where the event has happened. In figure 5.13 below, a communication failure with PLC has occurred on 05.12.2016 at 14:27 at the position X: 254.29; Y: 934.79. The map of the container terminal is used as a background for the co-ordinates to make it easier to understand where the event really has occurred.

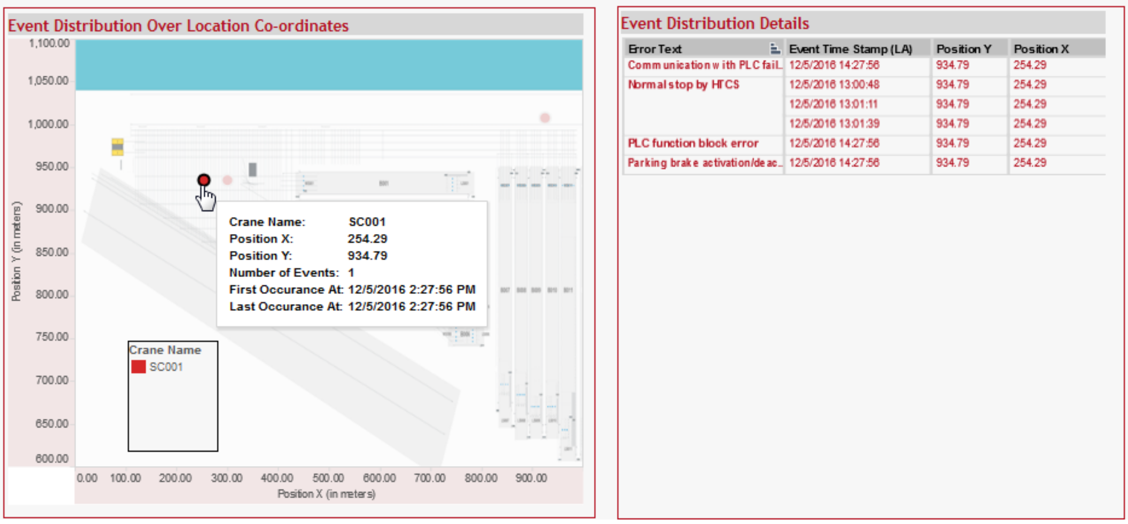

Figure 5.14 *Location data is utilized to define where the event has happened.*

Not only technical functionality issues are monitored, but also safety related information, such as “A truck might be stuck on the container”. These kinds of issues are usually simply caused by unopened or jammed container locks in the truck. The crane should automatically recognize that the truck is being lifted with the container and stop lifting immediately. However, if an automated crane starts to lift the container with a truck jammed to it, a dangerous situation is created. Even if there were not any humans in danger, something might always break and cause an economic damage. Still, this relatively often occurring event should be avoided by doing some development work on cranes or trucks. The bar diagram below (figure 5.15) shows that the event has occurred 16 times during the day.

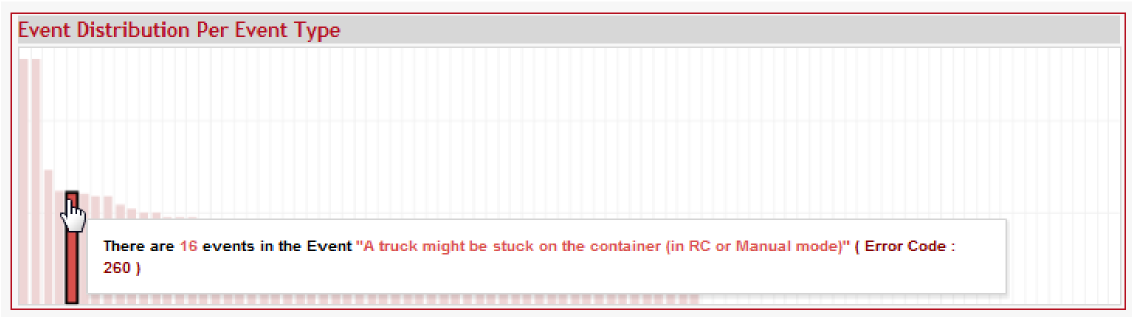

Figure 5.16 *Safety related events are also monitored, such as a truck that might be stuck on the container while the crane is starting to lift the container.*

Terminal traffic and efficiency is visualized by tracking containers in the terminal. Figure 5.17 below illustrates, how many container moves are performed by one ASC block per hour. The bar diagram uses two different shades of blue to refer to two different ASCs in the same block. The lighter shade refers to the waterside ASC and the darker shade refers to the landside ASC. Here the peak hours are between 14:00-17:00 and 19:00-21:00. On the left hand side, the summary shows how many containers are moved in total and how many containers have arrived to the block and left from the block.

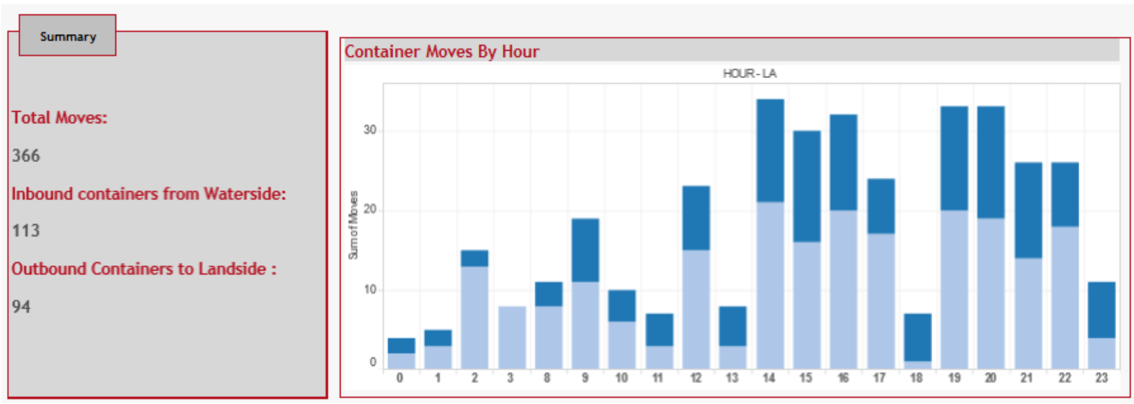

Figure 5.18 *Container moves per day for ASC block. Two different shades of blue are for two automated stacking cranes in the block.*

The moved containers are measured during crane operations. Figure 5.19 below illustrates the distribution of container lengths as a pie chart and the distribution of container weights as a bar diagram. In the pie chart, the brown color refers to a 40 feet, grey color to a 20 feet and red to a 45 feet long container. Different shades of blue in the bar diagram, again, refer to landside and waterside ASCs. For example, 66 pieces of 4 ton containers have been moved during the day, and 38 of the containers are for waterside crane and the rest for the landside crane.

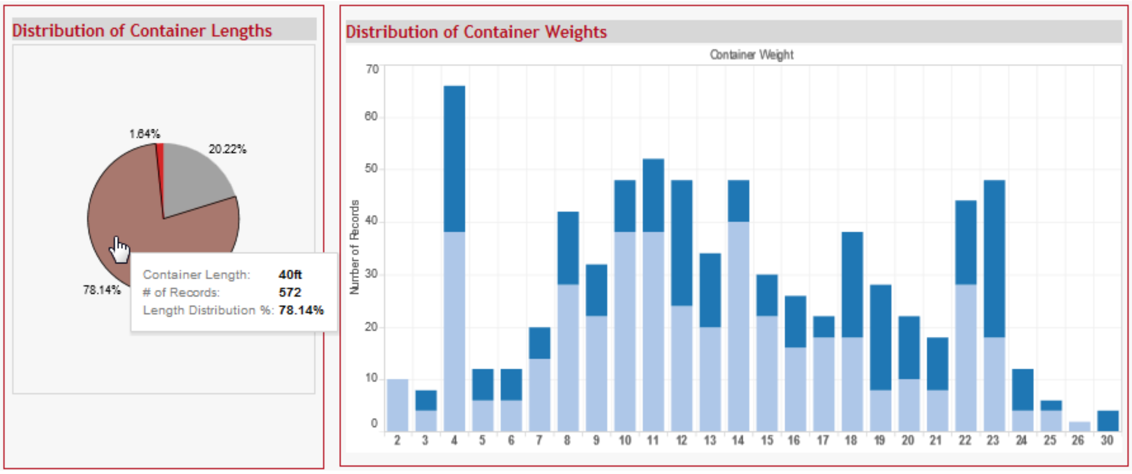

Figure 5.20 *Visualization for distribution of container weights and lengths.*

The crane subsystem fault analysis dashboard (figure 5.18) below shows an overview of errors in the cranes. Every crane has two indicator lights: the left one is a long term indicator and the right one is a short term indicator. For example, if the short term indicator is green and the long term indicator is red, it means that everything is OK at the moment but there have been relatively many errors recently. A yellow indicator means that there are or have been 1-5 errors. In the figure below, the crane ASC009L has had errors in the Spreader sub system, but the problem has been fixed. By clicking the indicator light, it is possible to drill down and see when and what has been causing the error in the Spreader.

***Figure 5.21** Crane ASC009L has had some errors related to Spreader.*

The error trend graph (figure 5.22) shows when and how many errors have been generated in the Spreader. The latest error has been generated on 14.12.2016, at 06:12. About two hours earlier, there have been two different errors generated at the same time. By clicking a dot on a graph, it is possible to see what error has been generated.

***Figure 5.23** This graph shows when and how many errors have been generated.*

Finally, a detailed error analysis table (figure 5.24) shows what has happened. In this case, there has been a communication break to the spreader control system. This kind of error can be caused, for instance, by a loose Ethernet cable or a mistake in switch configuration.

Detailed Error Analysis - Time Zone (LA)					
Crane Name	Sub-System	Error Text	Error Class Description	Error Code	Alarm TimeStamp
ASC009L	Spreader	Communication break to spreader control system	Auto reset Fault	928	14-Dec-2016 06:12:20 AM

Figure 5.25 *Communication break to the spreader control system was causing the error.*

It is also possible to see all the errors from the crane as a compilation (figure 5.26). ASC009L has been generating quite a lot of errors, and the table below is reduced to give more a clear example of the errors. A communication break to the spreader control system can also be seen on this table.

ASC009L	Communication	Null	Null	Null	Null
	Gantry	Null	Null	Null	Null
		Gantry fix frame brake 1 control monitoring error	Fault	335	14-Dec-2016 04:42:11 AM
		Gantry fix frame brake 2 control monitoring error	Fault	336	14-Dec-2016 04:42:11 AM
	Spreader	Null	Null	Null	Null
		Communication break to spreader control system	Auto reset Fault	928	14-Dec-2016 06:12:20 AM
					14-Dec-2016 06:11:58 AM
					14-Dec-2016 04:42:43 AM
					14-Dec-2016 04:42:01 AM
					14-Dec-2016 04:39:29 AM
					14-Dec-2016 04:39:25 AM
		Spreader not connected	Auto reset Fault	892	14-Dec-2016 06:10:04 AM
					14-Dec-2016 04:42:06 AM
					14-Dec-2016 04:41:39 AM
		Spreader stop activated	Auto reset Fault	727	14-Dec-2016 06:12:15 AM
					14-Dec-2016 04:39:25 AM
		Spreader telescope 40 ft indicated outside position limits (Limping)	Fault	884	13-Dec-2016 11:42:46 PM

Figure 5.27 *It is also possible to see all the errors from the crane as a compilation. A communication break to the spreader control system is underlined.*

The fault percentage dashboard (figure 5.22) shows what has been causing the most of the errors on each crane. For ASC009L, the most of the errors (46 %) have been generated by the LPMS (Load Position Measurement System) subsystem.

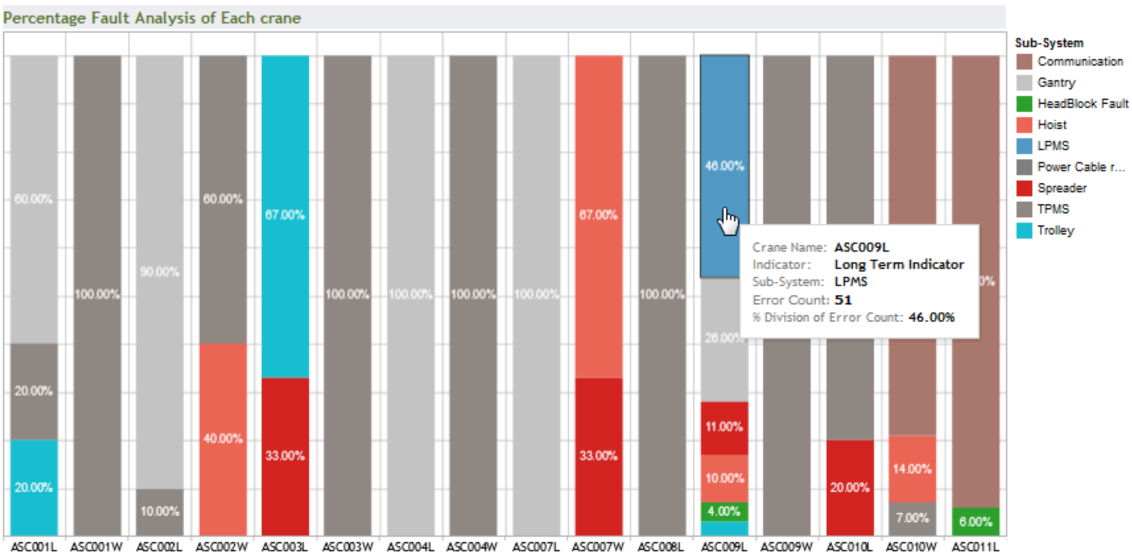

Figure 5.28 *Percentage Fault Analysis of Each crane*

As the figures in this sub-chapter demonstrate, there is a lot of data available on cranes and their operation in Kalmar Cloud. This data could be utilized, for example, by Kalmar’s customers or technical support team.

5.7 Remote center vision

The remote center at Kalmar could be made into a more interactive working environment, for example, by utilizing large touch screens as tables or walls. The screens could be used for monitoring and visualizing data in a more interactive way, so that it would be quicker to analyze and understand the data. Figure 5.23 below gives an example of large touch screens. Basically, the screens are large tablet computers that run, for example, a Windows operating system.

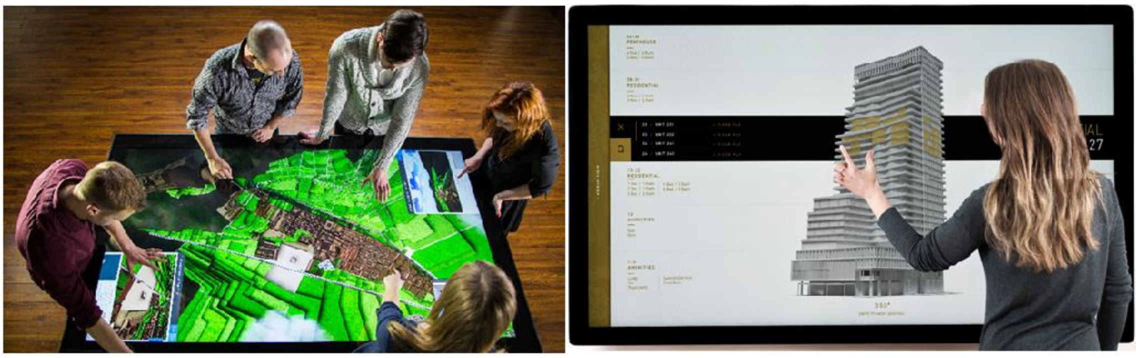

Figure 5.29 *Touch tables and walls can be used to make the remote center more interactive.(Ideum 2016)*

Data visualization could be improved by using an interactive world map which would present the overview of the monitored container terminals. All locations of monitored terminals are displayed on the map. If new alarms are generated in the terminals, an alarm indicator would appear on the map. Clicking the indicator opens a new window, which shows the layout picture of the terminal. Through the terminal layout it is possible to see, which crane or machine is causing the alarm. Clicking the crane opens another new window, which shows the detailed data visualization and what has happened, for example, during the last month. Figure 5.24 below illustrates the idea. The basic idea here is that the user can drill down to more and more detailed data.

Figure 5.30 *A vision illustration for data visualization. The user can drill down to more and more detailed data.*

It is important that the monitor can be used on any platform, not just on large touch screen, but also on laptops and mobile devices, because all Kalmar employees should be able to view the data easily in all situations. This is also important when demonstrating the remote monitoring concept for the customers. The customer may not always be able to travel to Tampere. Therefore, it is essential that the demonstration can be given on any device in any location.

However, a large touch screen creates a futuristic feeling for the remote center, which is desirable as the center is designed to be a ‘show room’ for Kalmar’s new technology. Large screens can also be used as cyclic displays that are showing different data views sequentially, such as world map or other overviews of data collected from terminals. These cyclic overview monitors should not be used for displaying detailed data from the cranes. The deeper data analysis would be done on the regular desktop PCs or laptops. The larger screens should display data such as: “Are there any active alarms?”, “How many cranes are remotely monitored currently?”, “Are remote connections to the terminals working?” and “How many containers are the terminals handling daily?” Some of the overview data could be displayed at same time, if the screen is divided into several areas.

The remote center creates new business possibilities for Kalmar. Remote monitoring can be offered as a service for a customer who wants to be sure that the machines are working efficiently, that downtime is reduced to minimum and that safety is enhanced to maximum. As a basic service Kalmar could offer, for example, a monitoring and reporting type of service. This would basically mean that Kalmar would collect data from the equipment and then give, for example, a monthly machine status report for the customer. This could be expanded by offering alert notifications for the customers by email or SMS, when something critical, like an emergency stop, occurs on the crane.

Another possibility to create new business would be offering technical support for the cranes remotely. Technical support specialists can analyze the collected data and try to solve the problem with the crane without travelling to the customer site. Existing remote connections can also be utilized to connect to crane PLCs, computers and network components to see what is wrong with the crane more specifically. If the problem with the crane can be solved by utilizing collected data and remote connections, it saves money for the customer and Kalmar. Customer saves money when downtime is reduced and Kalmar saves money when there is no need to send experts to the customer site, which can be on the other side of the world.

Kalmar’s sales personnel could use the collected data for targeting potential buyers. Monitored machine data can be utilized to estimate when the customer will need new spare parts and what amount of parts have to be in stock to be able to offer good customer service by offering right parts at the right time. Data collected from the machines can also be an effective way to collect valuable information from the customer. The data can be used, for example, for upsells and reorders. The sales team could, for example, point out which products the customers are currently using and might therefore want to buy a related product as well. A further example could be pointing out that certain parts of a machine are wearing out soon, which would create a need for purchasing new ones. When the customer sees that Kalmar is paying attention to them, they will more likely be willing to continue business in the future.

Kalmar’s R&D could use the collected reliability and environment data to recognize possible development areas in the machines more easily. For example, if some parts are wearing out too quickly, redesign may be needed or the parts may simply be changed to more durable ones in the next design cycle. On the other hand, some parts can also be of too high a quality, which can increase the price of the machine too much, and they should be changed to cheaper ones, if possible.

6. CONCLUSION

This thesis introduced a remote monitoring concept and how it can be utilized in an industrial environment. This thesis studied also the possibilities that remote connections and remote monitoring data could offer for the container handling company Kalmar.

Maintenance and support sectors are often seen as the ones to benefit the most from remote connections and monitoring: predictive or proactive maintenance would not be possible without collecting machine data and technical support can easily see lot of benefits when they are able to connect remotely to a machine they are working on. However, other stakeholders, such as sales and marketing, research and development, customer and even subcontractors can also benefit from the collected data.

To make it possible for all previously mentioned groups to utilize the data, it is important that the data is easily available and understandably visualized. Even if data is collected on some level, it is possible that only a very limited group of people even knows that it is being collected. However, when the data is finally available for all of the stakeholders, the most interesting question to ask is: What actions should the people take with this information? For example, sales and marketing could use the data for targeted marketing and reorders and R&D could use it to recognize possible development areas in the machines more easily. Customers could view the KPI values of the terminal they are operating and improve safety, since data collection helps to optimize the maintenance schedule and offers information on potentially dangerous situations. Different stakeholders might have different needs but they all could still benefit from the data in some way. It is important to notice that not all data is useful. Recognizing the useful data can be a challenge, because the stakeholders might not even know what kind of data would be useful for them.

During this thesis work, a demo version of remote center was built at Kalmar’s Tampere Technology and Competence Center. The main purpose of the remote center is to create a working place which could also be used to demonstrate for Kalmar’s customers what remote monitoring and remote controlling really mean. The demo version is a quite modest-looking room and it could still be improved a lot. In the future, the room could be made more impressive and more visual, for example, by using interactive touch walls or tables to better visualize the possibilities of remote monitoring. Also a well-planned monitor screen layout and properly chosen graphs or diagrams could have a great effect on the visual appearance of the data. There is also a possibility of moving the remote center to more impressive facilities on another floor at the Technology and Competence Center. However, even though Kalmar has opted for a physical monitoring room, monitoring of equipment fleets around the world does not necessarily require any physical remote center but rather a virtual remote center which can be reached from anywhere at any time. This basically means that the visualized data can be viewed and remote connections can be established from employees' laptops or mobile devices.

New technologies, such as wireless communication, vibration data analysis and mobile navigation applications for container terminals can create new possibilities for machine monitoring and connections. Ultra-Reliable and Low-Latency Communications (URLLC) is a new wireless communication technology in the industrial telecommunication field where deterministic low- latency communication is often required. Wireless control communication is a desired technology in container terminals, as it would make the deployment of cranes and modification of terminals much more flexible. In addition to controlling the cranes, URLLC could be utilized in streaming terminal monitoring video and monitoring data. Furthermore, URLLC could offer cost savings, because it does not use licensed frequencies, unlike radio controllers.

LoRa is a wireless, low-cost machine-to-machine technology which offers low-powered sensors and other modules the possibility to utilize sub-GHz frequencies to communicate through multiple gateways to a network server. LoRa is not applicable for remote controlling of cranes, but it is a promising technology for transferring non-real-time monitoring data from the cranes, such as vibration data from motors or bearings. Vibration data analysis can provide new possibilities, especially for predictive machine condition monitoring applications. Vibration data analytics could be utilized, for example, to predict if a bearing is going to wear out or a motor is in need for service.

The Kalmar mobile navigation application creates new possibilities to monitor and guide individual crane operators in order to enhance working efficiency in a container terminal. For example, at busier times the work load could be divided so that the terminal is better utilized and the safety could be increased by warning the operators of congestions and dangerous areas at the terminal.

Monitoring and supervising of any industrial application can create a better overview of operations, machine utilization and conditions. Kalmar is developing new ways to monitor and collect information from container terminals, which can be utilized in many ways by many stakeholders. Remote monitoring and connections are providing a lot of potential to create new business opportunities, to develop better container handling machinery and to provide better maintenance for automated container handling terminals. However, a lot of work still needs to be done before the full potential of remote services can be utilized.

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