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Data-driven planning and prioritisation in maintenance

A case-study in the automotive industry

Master's thesis in the Master's programme Production Engineering

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Gothenburg, Sweden 2019

MASTER’S THESIS 2019

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ABSTRACT

Developments in computerised systems and digitalisation are pushing industry into the next industrial revolution, Industrie 4.0. The developments have pushed the maintenance organisation at Volvo Cars Torslanda to evolve their maintenance practices within data-driven decisions in planning and prioritisation of maintenance, through collaborating in research projects. The result of the developments was a decision support tool that uses data to automatically in real-time identify bottlenecks in the production systems, with the aim to prioritise the bottlenecks to increase the productivity of the factory. The system was implemented in the body shop at Volvo Cars Torslanda, but the developments stopped there. The thesis picks up where the development ended in order to identify organisational factors that are constraining the use of data-driven decisions in planning and prioritisation of maintenance, both considering the earlier developments but also on a broader scale. Further, to identify if data quality is sufficient for data-driven decisions. Through a questionnaire and interview-study it was identified that low data quality and insufficient support systems affect the trust to and use of data-driven decisions, which are constraining factors for transcending into a more data-driven organisation. However, it was identified that there is a drive for wanting to become more data-driven and a need for better prioritisations. The assessment of data quality performed through interviews with experts and an analysis of datasets, concluded in that the general data quality regarding context independent problems were sufficient but that there is improvement for context dependable issues that are only identifiable by the staff working in the daily operations. The overall result is that there is a need to improve the data quality in the support systems and to educate users how to fully exploit the systems, in order for Volvo Cars Torslanda to transform into being a data-driven maintenance organisation. If the industry and Volvo Cars Torslanda overcome the identified constraints there is a potential to be succeed in the transformation becoming more data-driven within maintenance, thereby taking the step into the future of maintenance.

Keywords: Smart Maintenance, data-driven maintenance, maintenance planning, maintenance prioritisations, decision support, machine criticality, constraints to data-driven maintenance.

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ABBREVIATIONS

CMMS - Computerised maintenance management system
DQ - Data Quality
FMEA - Failure Mode Effects Analysis
FMECA - Failure Mode Effects Criticality Analysis
KPI - Key Performance Indicator
MCBF - Mean Cycles Before Failure
MDT - Mean Downtime
MES - Manufacturing Execution System
MOW - Maintenance Opportunity Window
MTBF - Mean Time Before Failure
MTTR - Mean Time To Repair
OEE - Overall Equipment Effectiveness
PLC - Programmable Logic Controller
PM - Preventive Maintenance
RM - Reactive Maintenance
SD - Standard Deviation
TA - Torslanda A-factory: The Body Shop
TB - Torslanda B-factory: The Paint Shop
TC - Torslanda C-factory: The Assembly Shop
VCC - Volvo Car Corporation
VCT - Volvo Car Torslanda
VD - Virtual Device

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1 INTRODUCTION

This chapter introduces general background about the industry and specific research topics relevant for the thesis. Further the aim and limitations of the thesis is presented, and the company that the thesis is collaborated with.

1.1 Background

Automotive industry is world leading in pushing manufacturing development forward. Due to a highly competitive market, companies in the automotive industry constantly seek ways to reduce costs. Generally, in production, maintenance accounts for 15 to 40 percent of the overall production costs and as maintenance is an area with historically low efficiency there is high potential in reducing overall costs (Löfsten, 1999). Developments is pushing the industry into the next industrial revolution *Industrie 4.0*, with it comes developments that changes the boundaries and possibilities of production. Prominent developments in data analytics and increase of utilisation of data has improved the visibility and knowledge of production systems. This enables more fact-based decisions, which improves both the day-to-day operations as well as long-term improvements. Maintenance has despite of development not improved significantly and research suggests that overall equipment effectiveness of bottleneck stations has not improved in Sweden for the last decades (Ylipää, Skoogh, Bokrantz & Gopalakrishnan, 2017).

To improve their maintenance practices, Volvo Car Corporation (VCC) has collaborated in research projects (Chalmers University of Technology, 2016; Vinnova, 2017). Focus of recent projects at Volvo Cars Torslanda (VCT), has been on developing a framework for data-driven maintenance planning and prioritisation. An important aspect of the research is to use data-driven decisions in planning of maintenance rather than relying on human decisions (Gopalakrishnan, 2018). The framework promotes a fact-based holistic approach for planning and prioritising maintenance which could increase both overall equipment effectiveness and productivity in production. Which in turn could improve the maintenance practices at VCT. Research has shown that most of the companies within the manufacturing industry prioritise maintenance, but fewer sets the machine criticality. Machine criticality is often set based on human decisions and is not used for setting priorities (Gopalakrishnan, 2018). Thus, without using the proper machine criticality to prioritise maintenance, there is a risk that priorities are not based on facts.

Although the collaboration between VCT and academia with research projects, there is still a gap between what is practiced and what is researched about. The gap between research and practice is not something unique for VCT as it is identified by researchers to be industry wide within maintenance (Bokrantz, Skoogh, Berlin, & Stahre, 2017). In this thesis steps will be taken in reducing the gap between VCT and implementation of data-driven maintenance planning and prioritisation. The specific topic under investigation is using data-driven bottleneck identification combined with machine criticality for prioritising maintenance in the planning phase. VCT see an opportunity in data-driven decisions as to increase cost savings and throughput, to improve competitiveness. To achieve this VCT must transform from an experience-based organisation to a data-driven organisation, where decisions are based on facts over intuition.

1.2 Purpose and Aim

The thesis will follow up on previous research in data-driven maintenance planning and prioritisations, to reduce the gap between VCTs maintenance practices and current research. The purpose is to uncover the inherent organisational constraints and challenges for transforming a maintenance organisation from being experience-based to data-driven in decision making. In addition, the purpose is to provide industry and academia with examples of what challenges might exist in organisations for transforming a maintenance organisation into being more data-driven. The aim will be to investigate VCTs maintenance organisation's readiness to adapt data-driven practices in maintenance planning and prioritisation, and to investigate if data quality (DQ) is a hindrance for taking reliable data-driven decisions. Moreover, the aim will be to understand why VCT does not use all data-driven decision support that exist and what support is missing for satisfying future needs. The intent is to investigate how workforce, culture, organisational structures, support systems and existing data affect the use of data-driven decision support and the transformation into being more data-driven. Lastly, the purpose is to provide VCT with knowledge about the implications of the existing constraints. In summary the purpose and aim of the thesis is to fill in the gaps between the problems existing and VCT and the future needs, as seen in Figure 1. The research will provide the maintenance organisation with guidance to become more data-driven in decision making in maintenance planning and prioritisation.

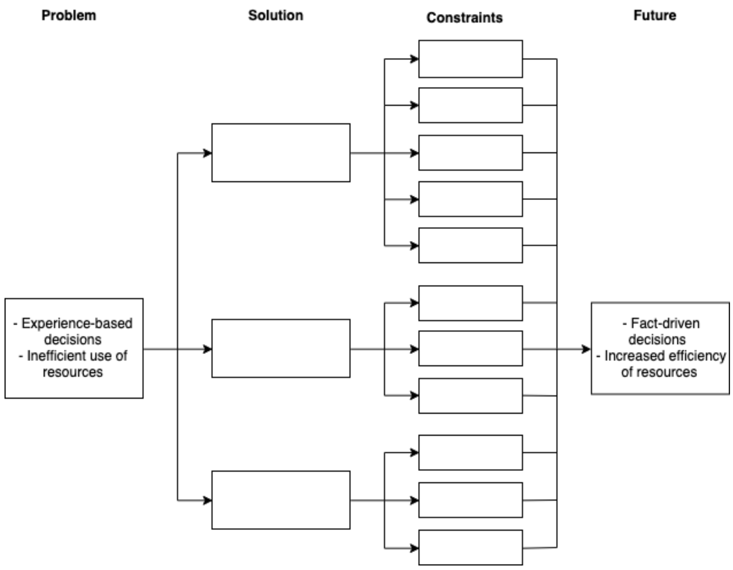

Figure 1. Illustration of the gaps between current maintenance practices and future needs in data-driven maintenance.

1.3 Scope and Limitations

The scope of the thesis will be to understand the organisations readiness for data-driven maintenance prioritisation and investigating whether the DQ in the organisation is sufficient for this. There will be no development of any frameworks or models for planning or prioritisation of maintenance; no simulations, implementations or empirical validations will be performed. The thesis will only cover a brief theoretical background and no extensive literature review, as earlier research projects already have covered it. Included in the scope will be maintenance prioritisations for reactive maintenance (RM), preventive maintenance (PM) and maintenance improvement activities such as eliminating failures. Lastly, the thesis will only cover the VCT factory with emphasis on the body shop and will not include other locations or companies in the investigation.

1.4 Specification of issue under investigation

The thesis will investigate the applicability of earlier research about data-driven maintenance planning and prioritisation at VCT. The following two research questions aim to provide a knowledge regarding organisational challenges of the research:

RQ1: *What are the organisational requirements and constraints of data-driven maintenance planning and prioritisation?*

RQ1 is created to answer what the underlying reasons are to why VCT does not use the existing decision support systems for taking more data-driven decisions and to understand if support is missing. The purpose is to provide VCT with awareness regarding the organisational problems that are hindrance for working with data-driven decisions in planning and prioritisation of maintenance.

RQ2: *What are the effects of data quality for decisions in data-driven maintenance planning and prioritisation?*

RQ2 is created to determine if the DQ is a hindrance for working with data-driven decisions in maintenance and what flaws might exist in the data. The aim is to understand how DQ is affecting the reliability of decisions and how it affects the extent to which data is used for decisions in maintenance. Further, the aim is to determine if the DQ is sufficient for satisfying future needs.

1.5 Volvo Car Corporation

Volvo Car Corporation is a global car manufacturer, founded in Sweden in 1927, and has sales in more than 100 countries. VCCs yearly net revenue for 2018 amounted to 252 MSEK according to Volvo Car Group 2019 annual report. The company has eight factories around the world which together produce more than 642 000 cars per year (Volvo Car Group, 2019), where almost 300 000 in the VCT. The factory at VCT is split into three parts; body shop (TA), paint shop (TB) and final assembly (TC), and employs about 6500 people (Volvo Car Group, 2019).

2 THEORETICAL FRAMEWORK

This chapter presents common maintenance philosophies and provides some specific background to the case.

2.1 Maintenance engineering

Historically, maintenance has been seen solely as a support function for manufacturing companies (Mobley, 2008; Ben-Daya, Kumar & Prabhakar Murthy, 2016). However, maintenance and its importance in the industry has transformed a lot over time. Over the last half-century, it has evolved from being seen as a necessary evil (Mobley, 2008; Löfsten, 1999) to becoming an important part of the strategy for companies to stay competitive in a constantly changing and demanding global market (Murthy & Kobbacy, 2008). A definition of maintenance is as follows; *"Maintenance is the combination of all technological, administrative, and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it may perform the required function"* (Ben-Daya et al., 2016). The maintenance costs represent a major part of the total production costs (Mobley, 2008; Löfsten, 1999). A contribution to why the maintenance costs are so significant is partly because of poor maintenance management and lack of fact-based decisions in planning. The amount of research about maintenance has increased significantly over the last years and suggests that data analytics should be used to a bigger extent to be able to make data-driven decisions rather than basing decisions on experience (Baum, Laroque, Oeser, Skoogh & Subramaniyan, 2018; Gopalakrishnan, 2018). Due to recent trends in digitalisation and an increase in research, maintenance organisations are expected to be highly productive and resource efficient. However, gaps have been identified between research and practice (Gopalakrishnan, 2018), a challenge that many companies are facing.

2.1.1 Maintenance philosophies

The two most commonly used philosophies to manage maintenance in the industry are run-to-failure management and preventive maintenance management (Márquez, 2007). However, the industry is moving towards predictive maintenance (Mobley, 2008), which is an approach when the operating condition is constantly monitored to be able to identify and perform maintenance just before the machine or tool fails (Lee, Lee & Kim, 2019). It is mainly done by using data and statistics to discover trends as well as the use of different tools to monitor vibrations and thermography (Mobley, 2008). The basic approach for the run-to-failure management philosophy, also called RM, is that "*if it ain't broke, don't fix it*" (Mobley, 2008). Thus, with this approach, no maintenance activities are done until the system or machine fails (Márquez, 2007). RM is associated with high maintenance costs and low machine availability, (Mobley, 2008). Accordingly, RM cannot fully be avoided, since it is not possible to schedule (Blischke & Prabhakar Murthy, 2003). PM management, on the other hand is a time driven approach where maintenance is performed to prevent the system or machine from failing (Löfsten, 1999). The approach to PM differs among companies. Some companies focus on activities such as lubrication and cleaning and some use more extensive programs with both lubrication and scheduled repairs to change parts before breakdowns would occur. Since it is time driven, it means that some repairs may be carried out for machines that do not have an urgent need for maintenance, which is costly. However, the cost of poor maintenance is even greater than not to do maintenance (Mobley, 2008; Ben-Daya et al., 2016).

2.1.2 Performance measurements

Performance measurement can be defined as *"the process of quantifying the efficiency and effectiveness of past actions"* (Neely, Adams & Kennerly, 2002). As maintenance costs represent a major part of the total production costs it is therefore in all asset-intensive industries of major significance to be able to follow-up and control the maintenance performance (Parida & Kumar, 2009). To measure and follow-up the performance, companies use different key performance indicators (KPI). Common KPIs are, technical availability, mean time to repair (MTTR) and mean time between failures (MTBF). However, the rapid development of new technology leads to new opportunities and challenges. Thus, the approach of solely following-up the mentioned KPIs is getting outdated and new performance measures are needed. Instead, it is important to focus on the whole production system rather than individual machines (Parida & Kumar, 2009). To reach a systems perspective other performance measures are needed, such as overall equipment effectiveness (OEE) and productivity (Ylipää at al., 2016). OEE is the product of availability, operational efficiency and quality rate (Ylipää et al., 2016), and can be used as an indicator to where maintenance should be allocated to increase the productivity of a production system. Productivity can be defined as output over input (Andersson & Bellgran, 2014) and is a typical measure of the number of products produced per hour planned production time (Almström, 2013). There are many ways to improve productivity, where common factors are method (M), performance (P) and utilisation (U) (Almström, 2013). Further, the equation; Productivity=M*P*U can be used to measure productivity, (Almström, 2013). Productivity is strongly related to how resources are utilised and can consequently be increased by producing more products with the same resources or to produce the same number of products with less resources (Andersson & Bellgran, 2014). The productivity measure is important to follow-up for manufacturing growth and competitiveness (Andersson & Bellgran, 2014), especially regarding the competitiveness towards low-cost countries (Almström & Winroth, 2010).

2.1.3 Computerised management systems

Managing decisions effectively regarding production and maintenance is often a complex task, which is why many companies use different computerised tools to support the decision-making process (Wienker, Henderson & Volkerts, 2016). A manufacturing execution system (MES) is a system used to collect, store and provide real-time data from a production system to serve as a decision basis in planning the production (Mehta & Reddy, 2015; Kletti, 2007). The data collected by an MES can be used in many ways e.g. track maintenance activities, provide detailed information about resource allocation and status, and information about product quality etc. (Mehta & Reddy, 2015; Kletti, 2007). A computerised maintenance management system (CMMS) on the other hand is a tool that collects data to support a maintenance strategy and to improve maintenance management. It is a tool that can support the daily planning of maintenance and identify crucial maintenance issues (Wienker et al., 2016).

When working with data and taking data-driven decisions, it is crucial to be aware of the DQ. The use of data can have a significantly positive effect on business results, while on the other side it may also impede the results if the DQ is not sufficient (Cai & Zhu, 2015; Pipino, Lee & Wang, 2002). To increase the positive effects of data-driven decisions, DQ assessment and improvement can be done to detect and eliminate data problems (Woodall, Oberhofer & Borek, 2015). If the stakeholders have a negative experience of the data, it will influence the extent to of how it is used (Pipino et al., 2002), thus an important part of the DQ assessment. Additionally, DQ issues will have an impact on the quality of decisions taken by the data (Pipino et al., 2002). DQ problems can be divided into four quadrants which are context-dependent with data perspective, context-independent with data perspective, context-dependent with user perspective and context-independent with user perspective (Woodall et al, 2015). Usual problems within each quadrant are seen in Table 1. Context-dependent DQ issues are those that lies within the given context of the data while context-independent issues are those which are general problems.

	Data perspective	**User perspective**
Context-dependent	● Violation of regulations ● Violation of constraints provided database administrator ● Violation of domain constraints	● Information not based on facts ● Lack of credibility ● Information is incomplete ● Information is hard to interpret ● Information irrelevant for context ● Information is outdated
Context-independent	● Spelling error ● Missing data ● Duplicated data ● Inconsistent data format ● Incorrect value	● Information is inaccessible ● Information is insecure ● Information is hard to retrieve

Table 1. Usual data quality problems divided by perspectives and type of problem (Based of Woodall, et al. 2015).

2.1.4 Future in digitalised maintenance

Smart maintenance developments and Industrie 4.0 is pushing new practices into maintenance organisations. Prominent areas are 3D-printing of spare parts, predictive maintenance through a large quantity of sensor data, and repair instructions through augmented reality or wearable displays (Bokrantz et al., 2017). In addition, due to the large connectivity of equipment to MES data is provided, which can represent the production systems in real-time and increase transparency of the processes (Bokrantz et al., 2017). In turn this provides the ability to further enable more decisions taken by data rather than experience. Taking decisions in maintenance on data rather than experience could increase the reliability of decisions and increase resource allocation (Gopalakrishnan, 2018). Moreover, in future maintenance organisations the focus will be on productivity rather than availability, focusing more on a system perspective of the production system rather than on availability of individual machine (Gopalakrishnan, 2018). The approach of doing this, is to further deploy data-driven decisions in maintenance for improving the system’s performance, by prioritising maintenance to bottlenecks, which constraint the production system (Ni & Jin, 2012). Lastly, implementation of new technologies is however not the prescription to all issues in maintenance organisations, and there is a large need to couple it with existing maintenance methodologies succeeding (Bengtsson & Lundström, 2018).

2.2 Maintenance planning & prioritisation

This subchapter presents theoretical background for maintenance planning and prioritisation. It introduces the terms bottleneck identification and machine criticality as well as related methods.

2.2.1 Maintenance prioritisation

In general, maintenance organisations face problems with limits in resources, creating a situation where all maintenance activities cannot be performed which leads to that maintenance activities have to prioritised (Chong, Mohammed, Abdullah & Rahman, 2018). Thus, prioritisation of maintenance is an important task for handling the limited resources and people available for performing maintenance work tasks (Ni & Jin, 2012; Li & Ni, 2009). In contrary to first-in-first-out (FIFO) approach for maintenance work orders, prioritisation of maintenance is the task of deciding in which order maintenance activities should be executed and this is done through coordination between production requirements and available resources (Dekker, 1995). In research it is mentioned that maintenance prioritisation should mainly be applied in work orders that could be planned in advance such as PM, as more variables are known beforehand (Dekker, 1995). However, with the rise of data-driven decision tools it has also been shown that prioritising RM with focus on productivity has high potential and large benefits (Li, Chang, Ni & Biller, 2009; Gopalakrishnan & Skoogh, 2018).

There are several goals with performing maintenance prioritisations, and common goals are increasing reliability, availability, cost efficiency and productivity (Gopalakrishnan & Skoogh, 2018). Reliability can become better as priorities can be set after risks analysis and failure modes, availability can become better by prioritising maintenance and cost can be reduced by prioritising in order to minimise costly breakdowns (Gopalakrishnan & Skoogh, 2018). Further, maintenance prioritisation can be used in an opportunistic way when maintenance opportunity windows (MOW) appear, which is cases where the system is either blocked, starved or when there are enough buffers for performing PM tasks without affecting the overall system (Li & Ni, 2009). Regarding techniques for prioritising maintenance, it can be in the form of a priority list or machine criticality, however, it is common to prioritise maintenance based on heuristic rules or experience (Ni & Jin, 2012).

2.2.2 Bottleneck identification

Bottlenecks in a production system are machines or work stations, among others, that are constraints that limit the overall performance of the system; constraints represent potential for improvement (Rahman, 1998). No system is free from constraints and focusing improvement efforts on lifting these constraints will have the effect of increasing productivity of the system (Rahman, 1998; Roser, Nakano & Tanaka, 2001). To focus improvement actions in lifting the constraints, bottlenecks have to be identified. There are several methods for bottleneck identification, some are utilisation (active time), waiting time and shifting bottleneck (Roser, Nakano & Tanaka, 2003). Utilisation, also called active time is identifying bottlenecks through the equipment with the highest sum of process time, downtime, repair time and setup time (Roser et al. 2001; Subramaniyan, Skoogh, Gopalakrishnan & Hanna, 2016). The waiting time method is by looking for the equipment where materials or parts have to wait in the longest time before being processed (Roser et al, 2003). The shifting bottleneck method is an elaborated version of the active time method, where the method distinguishes between sole bottleneck and shifting bottleneck. The shifting bottleneck is when two machines are bottlenecks at the same time (Roser et al, 2003).

The methods could later be applied using different techniques, two common techniques are *statistical-based* and *simulation-based* (Li et al., 2009; Li & Ni, 2009). The statistical-based technique is built on mathematical models and statistical assumptions in order to calculate where the bottlenecks are in the system (Li & Ni, 2009). The simulation-based method is performed by running simulations in a digital model, where simulated behaviors of the production system can be studied to identify bottlenecks (Li & Ni, 2009). The two methods are suitable for long-term analysis because of the statistical assumptions in the statistical method and its inflexibility in changes for the simulation-based method (Li & Ni, 2009; Subramaniyan et al, 2016). An additional technique is bottleneck identification through real-time data analytics which uses MES data in calculations, which could both perform long-term analysis of bottlenecks as well as analysing bottlenecks in real-time or close to real-time (Subramaniyan et al, 2016).

2.2.3 Machine criticality

Machine criticality is a tool that can be used to prioritise maintenance activities in a production system (Gopalakrishnan & Skoogh, 2018). Critical machines are those machines that have the most significant impact on the productivity of a production system (Gopalakrishnan & Skoogh, 2018*).* Thus, critical machines can be identified considering processing time, maintenance requirement, breakdowns, delay time, cost impact etc. (Pugazhenthi & Xavior, 2014). The two steps in setting machine criticality are that critical machines have to be identified and then classified. Important factors to consider in criticality assessments are environment, safety, quality and reliability (Gopalakrishnan & Skoogh, 2018).

There are different methods and approaches in which machine criticality assessment can be performed. Two common approaches are the experience-based and risk-assessment-based (Márquez, 2007). In the experience-based approach qualitative data is collected in interviews and questionnaires, which is used to gather experience, intuition and opinions of the workers in order to set the machine criticality (Márquez, 2007). This approach lacks in consistency and precision, but on the other hand it requires fewer resources. Thus, the approach is suitable when there is a lack of data, both with regards to quantity and quality (Márquez, 2007). In the approach for assessing machine criticality through a risk-based assessment, the risk of an asset is weighted to the amount of resources needed to maintain the asset (Márquez, 2007). It is an efficient model for setting machine criticality and cost-efficient to mainly target the riskful assets in a production system (Márquez, 2007). The assessment is done by multiplying the probability of failure with the consequence of the failure, which gives the risk concerned to the asset. To assess and to identify machine criticality, failure mode and effects analysis (FMEA) or failure mode and effects criticality analysis (FMECA) can be used (Gopalakrishnan & Skoogh, 2018), which thereafter can be used to classify the critical machines. Moreover, FMEA is a method used to evaluate and identify potential failure modes and to determine what the possible effects of a failure might be (Ringdahl, 2013). By using FMEA it is possible to analyse, ensure quality and improve manufacturing processes. In FMECA the failure modes identified are further analysed through a criticality analysis (Loznen, Bolintineanu & Swart, 2018). FMECA is often used when assessing machine criticality, to both identify the critical machines and to classify the level of criticality (Gopalakrishnan & Skoogh, 2018).

A widely used method for classifying the critical machines is the ABC or ABCD-classification method, where A is classified as the most critical machine and C or D the least critical machine (Gopalakrishnan & Skoogh, 2018). By identifying and classifying critical machines, maintenance can be prioritised to where it has the greatest effect with regards to the whole production system.

2.3 Data-driven planning and prioritisation of maintenance

Maintenance prioritisation can be a tool for improving production through reducing maintenance costs and downtime, while increasing productivity. As the productivity is strongly connected to utilisation (U) of the resources in a production system (Almström, 2013) and as maintenance prioritisation can increase the utilisation (U) of resources, productivity is important to follow-up. Thus, productivity can be used to measure the success of maintenance prioritisations. However, no or bad prioritisation of maintenance could have the opposite effect (Li & Ni, 2009; Ni & Jin, 2012). Although maintenance prioritisations being an important task, research has shown that many prioritisations in industry are situation dependent and rely on experience of maintenance personnel (Gopalakrishnan & Skoogh, 2018). In addition, maintenance planning often lacks system view of the production, focusing on availability of individual machines rather than improving the overall performance of the production system (Gopalakrishnan, Skoogh, Salonen & Asp, 2019a). The combination of lack of system view with experience-based decisions could therefore lead to decreasing productivity of the production system and poor allocation of limited resources.

In response to the lack of factful decisions and system view in maintenance prioritisation; methods have been developed to incorporate data-driven decisions support for planning and prioritising maintenance. One method for prioritising maintenance is through setting machine criticality after bottlenecks and prioritising maintenance to production bottlenecks (Gopalakrishnan, 2018). For detecting bottlenecks both shifting bottleneck and active time methods could be used. Shifting bottleneck method is superior to the active time method in terms of higher accuracy and possibility of detecting short-term bottlenecks, however it is more complex to use and to implement (Roser et al, 2003). As the algorithm uses real data it has the advantage of constantly using the latest available data to identify bottlenecks, while other methods rely on data based on historical records or on assumptions and approximations that might be inaccurate (Subramaniyan et al., 2016; Li & Ni, 2009). Further, the method has higher flexibility than simulations, since a production system may pursue transformations anytime and keeping a simulation model up to date is both time consuming and costly (Subramaniyan et al., 2016).

There are several issues with current machine criticality practices, these issues could be solved with a data-driven approach for machine criticality and its assessment. The first issue is a lack of trust in the set criticality, however by basing criticality on data this could counter the lack of trust (Gopalakrishnan & Skoogh, 2018). Additionally, machine criticality is often assessed on single-machine level rather than system level (Gopalakrishnan et al., 2019), which can have negative effects in maintenance prioritisation because criticality is not assessed relative to the best of the system. A further advantage of data-driven approaches for machine criticality is that there is potential in increasing productivity. Simulations have shown that prioritising RM by using the active time algorithm for setting static bottlenecks, productivity can increase by 5% (Li & Ni, 2009; Gopalakrishnan & Laroque, 2013). The productivity improvement can become even higher by incorporating the shifting bottleneck approach (Li et al., 2009). PM and improvement activities could also be prioritised according to the bottlenecks and show potential in improving productivity (Subramaniyan et al., 2016).

2.4 Change management

Change management can be defined as "*managing the process of implementing major changes in information technology, business processes, organisational structures and job assignments to reduce the risk and costs of change and optimise its benefits*" (Murthy, 2007). Change management is considered when there is a need to know why & how change happens and what needs to be done to make change a welcoming concept (Murthy, 2007). There are many reasons why organisations have difficulties in managing change; some common problems are bureaucracy, resources, skills and poor planning (Christensen, 1998). It can also be troubling if organisations perform the change too fast or too slow. Further, it is crucial for companies to stay updated with new technology and regarding what the common practices are within the industry. If not adapting to e.g. new technology on time companies suffer the risk of losing significant market shares (Christensen, 1998). Managing change successfully way is both difficult and important, since a common obstacle for change is that people have a resistance and lack will to participate (Kotter, 2007). Important steps, among others, to consider when performing a change is to communicate a vision and a strategy for reaching the vision, recognising short-term wins with the change, educate in the new process or behaviour and to motivate people in participating in the transformation (Kotter, 2007). Moreover, to be able to realise change, it is crucial that the people in the organisation accept and participate in the change, since resistance may obstruct the implementation (Thomas & Hardy, 2011). Lastly, to sustain change it has been shown to be important to have highly engaged management (Alänge & Steiber, 2009).

3 METHODOLOGY

The chapter provides a description of the methods and methodology used in the thesis and the overall structure. The layout of the chapter gives insight of the general methodology and mindset, and presents the methods used for answering each research question.

3.1 Research methodology

The research methodology was structured around the two research questions where both were investigated simultaneously and thereafter analysed combined. Afterwards the results were assessed together in in terms of what value it brings to academia as well as to VCT. The research methodology was designed to create a credible and strong result through triangulation, where each research question was triangulated by using different methods of data collection in order to provide answers not relying on only one data point (Denscombe, 2014). The triangulation was done through a mixed methods approach which combines both quantitative and qualitative data. The mixed methods approaches in this thesis were explanatory sequential design and exploratory sequential design (Cresswell, 2014). In the explanatory sequential design, quantitative data is gathered and analysed, to provide answers which later is explained and interpreted in depth with qualitative data. In the exploratory sequential design on the other hand qualitative data is collected and analysed to later be used to form a quantitative study, often where something is developed and tested (Cresswell, 2014). Conducting research with a sequential design has the strength of building the result through incremental stages of qualitative or quantitative data sources.

3.1.1 Workflow

The work was firstly initiated with a pre-study which aimed to gain an understanding of the current state which was used to form the research project. Based on the pre-study there was be two paths investigated simultaneously, one path for each research question. Afterwards, the research questions were combined in the overall analysis and result, to provide the answer to the overall scope of the research. The workflow is presented in Figure 2.

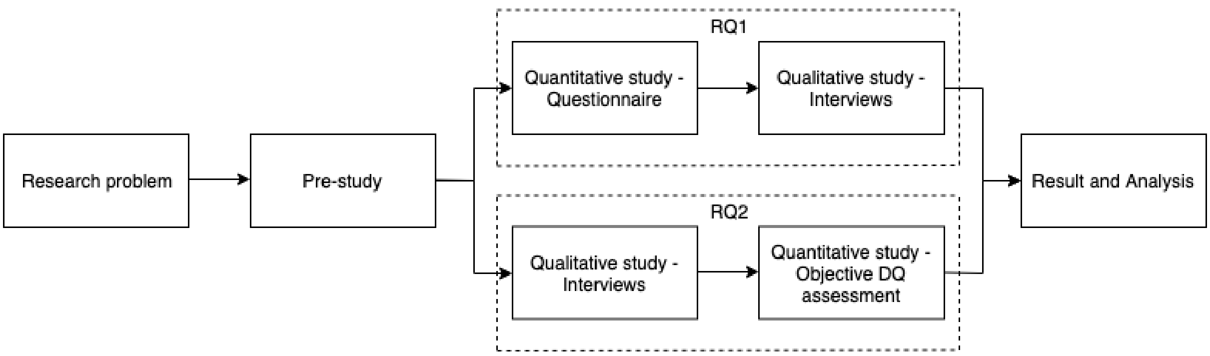

Figure 2. Chronological workflow of the key points in the research.

3.1.2 Research philosophy and world view

This subchapter aims at reducing misunderstandings by stating the researchers' philosophy and worldview. Creswell (2014) writes that stating philosophy and worldview is an important part of a mixed methods research, as it makes the reader aware of background for assumptions made in the research. In this research the objective of the researchers was to conduct research that could be beneficial for both academia and VCT, without compromising the research quality. The researchers aimed at reducing the gap between maintenance research and industry practice while providing new insights for academia. The philosophy of the researcher is pragmatic in a manner which is solution oriented and relying on facts. However, the researchers believe it is important not to lose the human aspects of research and not to forget that humans are complex with emotions that could be both rational and irrational. The researchers believe it is important to combine the fact-based evidence-driven approaches to research with an understanding of social aspects of humans.

3.1.3 Ethical standpoint

The research in this thesis was conducted with a predetermined ethical framework. The framework was inspired by the book *The good research guide* by Denscombe (2014), which overall aims at conducting research with participants best in mind as well as conducting research with honesty. In this research all participants were treated with respect and the aim of research was not to cause any harm to those participating. Further, all participation was to be voluntary and consent had to be given first. In order to achieve the protection of the participants, those who participate were informed of the research first, then they were give an informed consent and lastly their answers were anonymised to the extent possible. Before, during and after the research the researchers aimed to have good communication with management and participants, with the purpose to prepare the participants for the study and to give them a chance to get back with any questions or to discuss any uncertainties. The studies were totally anonymous to minimise the risk and possibility of tracing back data to a particular person. However, in some cases this was not always possible to as there were not be many people with the same job, which affected the possibility of anonymity. In those cases, careful attention was spent on communicating the increased risk. Lastly, the researchers aimed to conduct the research with honesty and integrity.

3.2 Pre-study

The aim of the pre-study was to perform a current situation analysis of VCT to provide understanding of the current situation for planning of maintenance and structure of the maintenance organisation. The knowledge gathered from the pre-study served as a foundation for the forthcoming research. The methodology for the pre-study was a combination of unstructured interviews and observations. The combination of the two methods was chosen as it provides a descriptive overview of the organisation, where the participants have freedom in expressing their free minds during the interviews and that the observations give a firsthand view of the organisation (Denscombe, 2014).

The selection group for the interviews consisted of the smart maintenance engineers from the plant maintenance department. Thus, the engineer responsible for development of maintenance processes in each shop respectively, and the engineer responsible for the maintenance planning processes. The smart maintenance engineers were chosen due to their knowledge about the maintenance work in the different shops and their overview of the maintenance organisation. By interviewing the responsible maintenance engineer for each shop, different perspectives could be identified as well as differences between the shops. The interview with the engineer responsible for the maintenance planning processes provided perspectives in PM planning and the existing planning processes. Two observations are conducted, at the control bridge in TA and TC, in order to provide understanding about how RM work orders were distributed and prioritised. The reason for choosing the two shops was due to the significant differences with regards to both complexity of the flows and level of automation. In addition to the interviews with smart maintenance engineers and the observations at the control bridges, an interview was conducted with the person globally responsible for the computerised management systems for maintenance purposes. This, to gain greater understanding of the systems to be able to for the forthcoming interviews and questionnaire.

3.3 Methods RQ1

RQ1: What are the organisational requirements and constraints with data-driven maintenance planning and prioritisation?

The purpose of RQ1 was to determine organisational requirements and constraints regarding data-driven maintenance planning and prioritisation at VCT. Further, the aim of the methods was specified to test the following hypotheses:

- There are more maintenance work orders than there are resources to cover them, therefore there is a need for prioritising between maintenance work orders. (Gopalakrishnan, 2018)
- Lack of competences and competence development in an organisation is a constraint for working more data-driven (Bokrantz et al. 2017).
- There is a lack of systems perspectives in maintenance organisations and focus is rather on machine level, which could reduce the overall system performance (Parida & Kumar, 2009; Gopalakrishnan, 2018).
- Prioritisations are mainly based on experience (Ni & Jin, 2012) rather than facts and data, which could result in bad resource allocation (Gopalakrishnan, 2018).
- When shifting to new work methods or implementing new computer systems, the workforce may oppose the change if there is a lack of trust to change (Kotter, 2007; Thomas & Hardy, 2011).

The methodology chosen followed an explanatory sequential research design, divided into two methods as seen in Figure 3. The purpose of using the explanatory approach was to explore quantitative data which was later explained further by qualitative data. The quantitative study was performed through a questionnaire, which had the aim to provide broad knowledge about requirements and constraints in the organisation for the investigated technology. In the second step the answers of the questionnaire were explained and elaborated with semi-structured interviews, which provided more in-depth answers to the quantitative data.

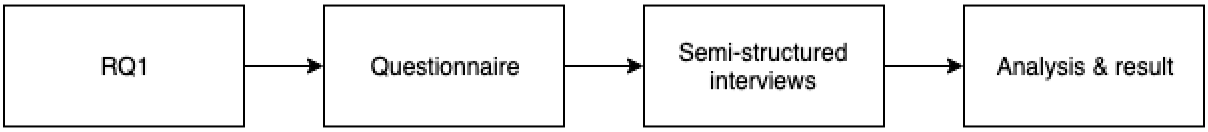

Figure 3. Research design for RQ1.

Questionnaire was the chosen method for collecting the quantitative results as it could provide quantifiable insights of workers experiences and perspectives of the organisation. Forming the study with a questionnaire as the base has the strength to find trends among thoughts of the workforce (Brace, 2013; Gillham, 2008) and with the quantitative output provide rigor to the study. By following up the questionnaire with a qualitative study, the data can be triangulated with different methods while providing explanations to the quantitative data (Creswell, 2014). The results from each method were analysed and presented separately.

3.3.1 Questionnaire

The objective of the questionnaire was to identify areas where there could be organisational constraints for working with data-driven maintenance. To identify the areas, six topics for questions were built based on literature and results of the pre-study, with each topic considering a number of questions that could identify further constraints. The six topics were *change management, data-driven decision, decision support systems, demand, prioritisations,* and *resources & competences*. In Figure 4 the different topics are presented with issues that are identified to form the questions. The topic of *change management* aimed to identify the perceived trust and value of technological developments in maintenance and whether there were any constraints in the workforce's perception of changes. The topic of *data-driven decisions* aimed to provide understanding regarding the extent to which data is used for decisions in maintenance, and the perceived value & trust. Further, to understand if the organisation was inclined of using data-driven decisions. The topic of *decision support systems* aimed to understand to which extent the support systems and its many applications are used, and whether the staff suggests that sufficient support is given. Additionally, to identify if implemented support tools identified in the pre-study are used. The topic for *demand* included questions to answer whether there are enough resources to perform the required maintenance work and if the resources are utilised efficiently, which aimed to answer whether there is a need for prioritising maintenance. The aim of the topic for *prioritisations* was to answer whether there is value in making prioritisations in maintenance, the attitude to the existing prioritisations and to identify if the staff think that they have knowledge in the bottlenecks in the production system. The sixth topic is about *resources & competences* and aimed to identify if the staff has the right skills to work with data-driven maintenance and whether there are sufficient amount of resources for competence development.

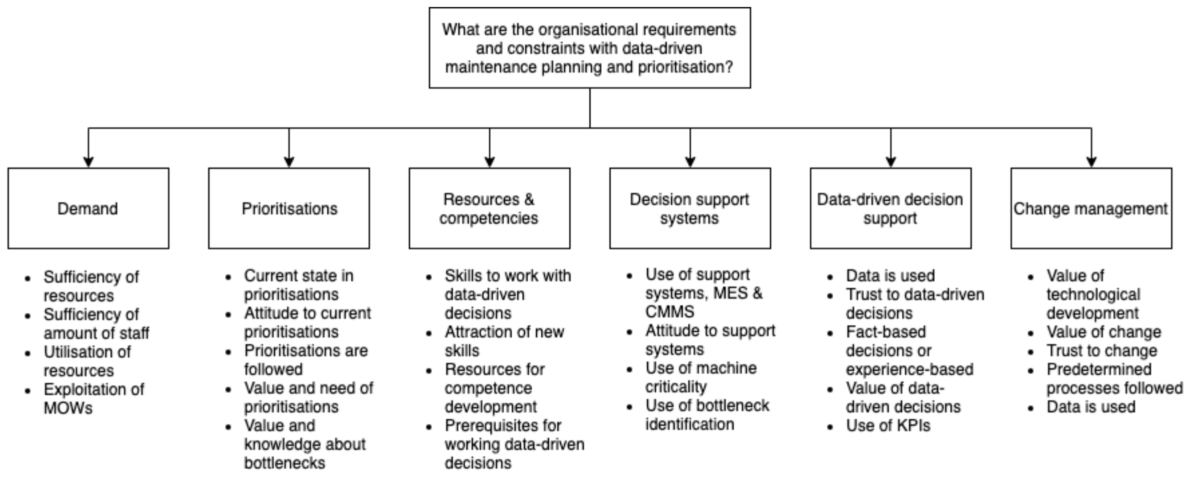

Figure 4. Issues covered by each topic in the questionnaire.

The questionnaire was formed with a descriptive survey research approach, which is an approach used to learn about the opinions for a certain population (Forza 2002). To achieve this and to reach out with the questionnaire to as large part of the selection group as possible, the questionnaire was formed electronically online and sent out to the participants as a web-based questionnaire by direct email. It is of significant importance to receive answers from as large part of the segment groups as possible to be able to make assumptions about the rest of the group (Denscombe, 2014), in order to get a representative result. The questions were slightly different depending on which role and shop or department, as to keep questions relevant for the participants. For each question, a five-point scale was given where the respondents were asked to choose the alternative on the scale which represents their opinions the most. The five-point scale is called *Likert scale* and provides the participants with the following alternatives, "*strongly agree, agree, neutral, disagree, strongly disagree*" (Denscombe, 2014). However, as for this questionnaire, a sixth answering alternative was provided to the respondents, "*don't know*", which the participants used when no of the five alternatives on the Likert scale fit their opinion or level of knowledge, the sixth alternative was not used in the analysis. The scale was used for enabling an easy analysis and comparison of the results.

To be able to cluster the answers and to understand different perspectives, the participants were divided into segment groups. The segment groups were local maintenance engineers, maintenance technicians, planners, preppers, group managers, and maintenance managers for each shop respectively. Additionally, the manager and smart maintenance engineers at the plant maintenance department were included. The groups were composed of different work roles and departments or shops, which had the purpose of getting a nuanced view of the maintenance work at VCT. Moreover, the participants represent perspectives from working with the operative execution of the maintenance work to management and development of future maintenance practices. Local maintenance engineers and technicians play an important part in understanding the maintenance work, since they represent the operative part of the maintenance work. Planners and preppers add knowledge of the requirements and constraints from working with planning and prioritisation. To get a perspective of the engineers that work more holistic for the plant the smart maintenance engineers were included in the selection group, which represents the overall development of maintenance work at the factory. Thereafter, both managers and group managers were added to provide the perspective from management. The purpose of including different shops, roles and the plant maintenance department was to be able to analyse the differences between the groups and to make statistical conclusions from the overall selection group.

The overall selection group is 271 persons, which was composed of staff from the plant maintenance department and the maintenance organisations in TA, TB and TC. The response rate is 72/271 which is 26,6% of the selection group. The response rate for each shop is presented in Table 2 and for plant maintenance in Table 3, with a distribution of answers for each role. Managers and group manager are in the same category as they are listed in the same category in the staffing lists.

	Technician	**Engineer**	**Manager & group manager**	**Planner**	**Prepper**	**Total**
Body shop (TA)	19/99 (19%)	5/7 (71 %)	2/5 (40%)	1/1 (100%)	1/2 (50%)	28/114 (25%)
Paint shop (TB)	12/62 (19%)	8/10 (80%)	3/5 (60%)	0/1 (0%)	1/2 (50%)	24/80 (30%)
Assembly shop (TC)	3/56 (5%)	7/9 (78%)	3/4 (75%)	1/1 (100%)	2/2 (100%)	16/72 (22%)
Total	34/217 (16%)	20/26 (77%)	8/15 (53%)	2/3 (67 %)	4/6 (67%)	68/266 (26%)

Table 2. Response rate for respective shop with number of respondents divided by the segment group and the response rate in percentage.

	Smart maintenance engineer	**Manager**	**Total**
Plant maintenance	4/4 (100%)	0/1 (0%)	4/5 (80%)

Table 3. Response rate for plant maintenance with number of respondents divided by the segment group and the response rate in percentage.

In the descriptive analysis there are two important things, to calculate central tendency and the measurement of spread, these two measurements are used in the analysis of the answers of the questionnaire. Central tendency provides a number of what most participants answered, and measurement of spread provides a number to which extent there is a consensus among the participants (Denscombe, 2014; Creswell, 2014). Both mean, and median is used for the central tendency, and for measurement of spread, standard deviation (SD) is used. A large SD means that people disagree with each other and smaller SD means that people are in more agreement. Practically for calculating these two values, the answers of the questionnaire have to be coded (Denscombe, 2014), as seen in Table 4 where the answering alternatives are coded in a scale of 1 to 5 with each alternative. The alternative "*don't know*" was not given any coding as its answers were not considered. To complement these two calculations, graphs were used to visualise the results. The graphs provided an easy and understandable representation of the data for both communicating the results as well as for analysing the results (Faber, 2012).

Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree	Don't know
1	2	3	4	5	-

Table 4. Coding of the answering alternatives in the questionnaire.

3.3.2 Interviews

The qualitative study was executed in the form of semi-structured interviews, which is a form of interview with predetermined questions but the flexibility of going deeper into certain answers and topics that were of interest for study (Denscombe, 2014). The interviews were conducted face-to-face with one interviewee at a time, with the aim to eliminate interviewees influence on each other's answers and to increase the possibility for the interviewers to pay more attention on the specific interviewee to build follow-up questions. The aim of the interviews was to further develop the answers of the questionnaire with more depth and nuance, thus the questions for the interviews were based on the analysis of the questionnaire data. The segment groups for the interviews were firstly the smart maintenance engineers with responsibility of development for each shop and personnel within TA. As the scope of the thesis was mainly for TA, the depth of interviews was held there. While the overall perspectives for TB and TC was provided by the smart maintenance engineers. Additionally, the smart maintenance engineers were chosen to provide answers overall for VCT because of their holistic overview of each shop and their understanding of the maintenance organisation. Interviews in TA were held with one of each roles of technician, engineer and planner from the maintenance organisation, as well as a maintenance manager. These interviewees provided insights and perspective of how the different roles in TA think but also provides knowledge of the general opinion of the whole shop.

Questions for the interviews were based on the analysis of the questionnaire, where the main topics identified were *data-driven decisions, decision support systems, development & change, prioritisations* and *maintenance & organisation*. Firstly, questions generally regarding maintenance and organisation were asked to gain a wide knowledge of how the maintenance organisation, further the general questions were asked in order to understand how KPIs are used for steering the organisation and to understand which systems and methods are used in the organisation. Within the topics deeper questions were asked in order to nuance the questionnaire data. Some questions aimed at creating an understanding of how the organisation base maintenance decisions, what is the foundation for prioritisations and how data is used. Other questions aimed to uncover obstacles for changes, development or working more data-driven. Additionally, some questions aimed at understanding how competences are in the organisation and if there are resources developing them. Lastly, some questions were asked in order to see if there is a need for a data-driven decision support for planning and prioritising maintenance or if the organisation has other needs. An expanded explanation of what each topic aimed to uncover can be seen in Figure 5. The topics also serve as tags to scope the analysis of the results.

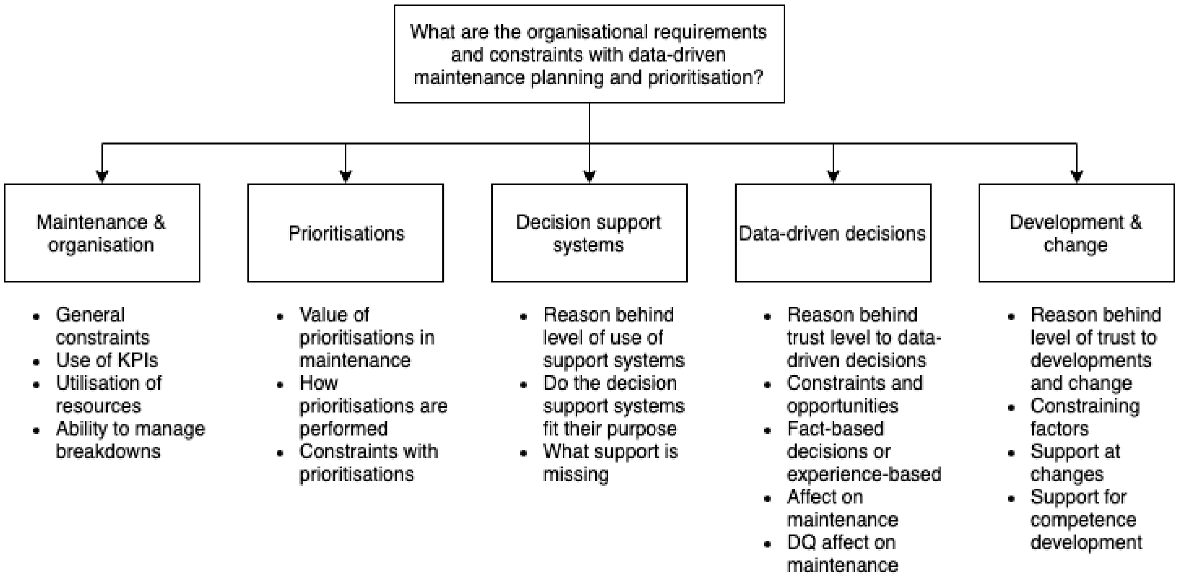

Figure 5. The primary tags for dividing the interview answers, together with what is included in the tag.

All interviews were recorded and then transcribed in order to enhance the analysis stage. Before analysing the answers, the transcriptions were read through where content was marked with a tag representing its content. Thereafter, all tags were used to categorise the relevant information in a spreadsheet where it is later sorted after the tags to create a synthesis of the gathered content. In the analysis the content was summarised and connections were drawn between the content. When the text was sorted the content was analysed and summarised in order to answer the areas that needed further explanation. The answers for the different shops and roles were compared in order to explain similarities and discrepancies in the data between them.

3.4 Methods RQ2

RQ2: *What are the effects of data quality for decisions in data-driven maintenance planning and prioritisation?*

The aim of RQ2 was to determine if the quality of the data at VCT is sufficient for data-driven decisions in maintenance planning and prioritisation, and to identify necessary improvements regarding the quality of the data. The hypothesis tested in the methods was to verify that the DQ at VCT is sufficient for taking data-driven decisions by, as taking decisions based on data with bad DQ can result in a lack of accuracy and harmful decisions (Aljumaili, 2016). The methodology was based on an assessment model that combines subjective and objective perspectives to assess the DQ, which is divided into a qualitative study for subjective assessment and quantitative study for objective assessment. The structure for the assessment followed an exploratory sequential design, as seen in Figure 6. The method used for the subjective assessment was semi-structured interviews, which had the aim to uncover workers experience and insight of the DQ. For the objective assessment, random samples of data were analysed to validate the subjective assessment.

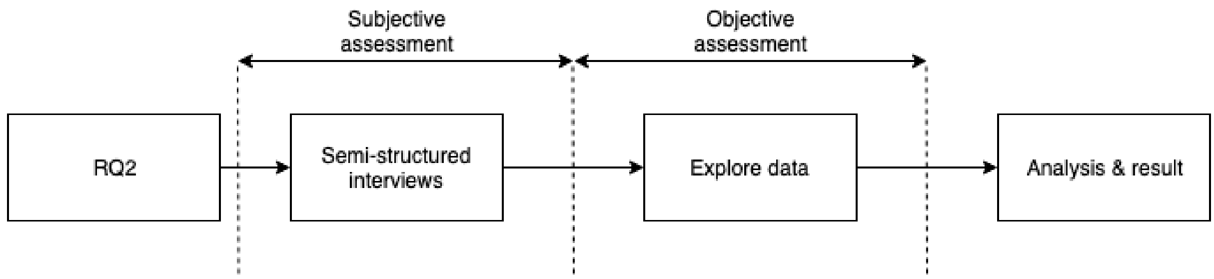

Figure 6. Research design for RQ2.

The two assessments were compared in order to combine an analysis of the actual data with the experiences of the organisation, in order to provide a deeper understanding of the DQ (Pipino et al., 2002). The research design was based on an exploratory sequential design, as the subjective assessment can be used to narrow the scope of the objective assessment and that the objective assessment can validate answers from the subjective assessment. Further, the subjective assessment used semi-structured interviews to find workers experience and insights of the DQ. In the objective assessment random samples of the data were explored in order to validate answers from the subjective assessment and to find further explanation in what errors might exist in the DQ.

3.4.1 Data quality indicators

For scoping the subjective and objective assessment five *dimensions* were used to form the investigation; the dimensions are *availability, usability, reliability, relevance* and *presentation quality of the data* (Woodall et al., 2015; Pipino et al., 2002). The dimensions can be elaborated in further depth into *elements*, which different *indicators* can be assigned to. Within each element there are different indicators that are used as criteria for assessing the DQ. The indicators represent different statements that are checked to assess whether the DQ is sufficient (Pipino et al., 2002; Cai & Zhu, 2015). A table derived from the proposed dimensions, elements and indicators (Cai & Zhu, 2015) is presented in Appendix A, which was slightly tweaked to match the case in this thesis. The indicators, elements and dimensions were used for forming both questions for the interviews and scoping the objective assessment.

3.4.2 Subjective assessment

The subjective assessment was performed through interviews with staff at VCT which is knowledgeable in the data under assessment. Interviews were chosen as method as it is an approach which provides deep answers from people who are acquainted with the data and its application. The interviews were held face-to-face in a semi-structured form in order to have flexibility while having predetermined questions. The interviews were held with people in three different roles, smart maintenance engineer, MES-specialist and IT-staff. By interviewing people with different roles, both the user and supplier relationship to the data is explored and which enables identification of discrepancies between roles (Loshin, 2011). The smart maintenance engineer provided insights of the user perspective of the data as the role uses the data to make decisions on a daily basis. While the local MES-specialist and the IT-staff provided knowledge and perspective of the supplier perspective, which enabled insights in how VCT works with quality assurance and improvement work of the DQ.

The questions asked in the interviews were questions based on common DQ-indicators established in literature, which can be found in Appendix A for a detailed description. The indicators were based on the DQ-elements *Accuracy, Consistency, Credibility, Integrity, Readability, Relevance, Completeness* and *Timeliness*. Thus, by covering all indicators, the aim was to perform a thorough assessment which gives detailed insights in the DQ. Some questions were directly aimed at assessing the DQ, some at the structures and format around data and some at identifying whether the data is up to date, among other questions. In overall, the questions were aimed to gain understanding of both the organisational side of DQ but also the individual experiences of the DQ. Further, by using the indicators for designing the questions the answers could directly be used to identify the state of the indicator.

The interviews were held with one interviewee at the time and to enable analysis and future work interviews were recorded and transcribed. As to explore important factors from the interviewee answers, the approach for analysing the answers was by tagging important quotes and paragraphs in the transcriptions during the analysis. After the analysis of the transcriptions, all text with tags were organised in a spreadsheet where the text is clustered after similar tags. The identified tags were *data format*, *data quality*, *quality assurance*, *quality improvement*, *data speed*, and *trust level*. Thereafter, all text was processed and analysed in order to describe how DQ and to identify areas on where to focus the objective analysis. Further, answers between the different interviewees were analysed to identify different views between functions, supplier and users. The analysed answers were later used to answer how the subjective assessment answers the statements in the DQ indicators.

3.4.3 Objective assessment

The objective assessment was used to validate the insights gained from the subjective assessment by objectively assessing the quality and comparing it. The validation was done with the aim to identify if the answers of the interviewees are different than reality and to find discrepancies or similarities between them. The objective was scoped to one line in TA which was considered to have data that is representative to the overall shop. The line was chosen randomly from a list of recommended lines with average DQ. There were two types of data assessed, first was all the cycle times for the machines in the chosen line and the second type was all the alarms from those machines. The data came from two types of datasets, one for the data that exist in the system that transforms all the programmable logic controller (PLC) data to a standard format and the second type was the datasets in the in-data for the MES. The two different datasets were compared to identify discrepancies between the two, which was used to see whether data is lost during or corrupted during transformation. The data that was assessed is historical data for the chosen line, ranging over a four-week interval between April and May 2019. The reason for having historical data was to be able to compare how the data is changing over a longer time period. Lastly, the main assessment of the data was to be using the DQ indicators and to objectively answer the statements by comparing them to the data. The comparison to the indicators were made on the dataset for the in-data to the MES, as it is the data that the MES use.

4 RESULTS OF PRE-STUDY

This chapter provides a summary of the results of the pre-study. The full result is found Appendix B for interviews and Appendix C for observations.

VCC is divided into several plants around the world which in general follow the same structure between plants with the same functions. The different plants share similar processes, practices and systems worldwide, which means that the innovation at one plant can be transferable to another. At VCT in each shop there is a local maintenance organisation responsible for the development and the operation of the maintenance in the shop. To support the local organisations there is a maintenance organisation called plant maintenance, which is responsible for alignment between the local organisations and development of new maintenance practices.

In each shop there is are different MES to monitor disturbances in the production system, which constantly keeps track of the production system. TA has the most modern and recent MES called Axxos [1], which will be the new standard for MES at VCC and will in the future be implemented in both TB and TC. Within Axxos there is a function named *active time*, which provides real-time identification of bottleneck machines in the production system. However, the function is not used at VCT but could provide the data support necessary for prioritising maintenance. The CMMS used at VCT is called Maximo[2], which is used for managing maintenance work orders and inventory control for spare parts. Within Maximo there is a function for setting criticality for work orders as support for prioritisation of maintenance. During the interviews it was mentioned that this function most likely is not used. Further, the machine criticality that exists in the system is allegedly not up to date. Additionally, there was an indication that Maximo is not used to the same extent as intended. Identified was that there is an indication that decisions in the organisation are more based on experience rather than data. An underlying factor mentioned was that the level of trust towards data could affect the level of data-driven decisions. An additional cause is that the many support systems are considered to be user-unfriendly.

In each shop there is a location, called *the bridge,* which is a location that has a visual overview of the shops and receives all alarms regarding RM. When the alarms reach the Bridge, the severity of the alarm is determined and prioritised accordingly. From the observations it was identified that in TA that there is not a large need for prioritising RM as the maintenance organisation seems to handle all breakdowns. The operator at the bridge mentioned that the prioritisations performed are handled by experience. In TC the number of requests for RM is significantly higher than in TA and the impression is that the operators have to perform more prioritisations between work orders. During interviews it was identified that PM is mainly prioritised by the planning organisation in each shop, where the planner prioritise through information given in Maximo.

[1] https://optiware.com/products/axxos-oee/
[2] https://www.ibm.com/products/maximo

5 RESULTS OF RQ1

In this chapter the results of RQ1 will be presented. The results of the questionnaire will first be presented followed by the results of the interviews. Thereafter, an analysis of the overall results is presented. In the part about the questionnaire there will be statistical commentary for all the questions.

5.1 Questionnaire results

The questionnaire was sent out through email to the maintenance organisations in TA, TB and TC, as well as to the smart maintenance engineers at plant maintenance. The respondents got ten days to respond to the questionnaire. During this period the staff got reminders of their supervisors and managers to respond to the questionnaire. Statistical commentary will be presented for all questions, but with only a handful of questions are presented with both tables and graphs. The full result for all questions can be found in Appendix D.

In total there were 72 respondents of the questionnaire. The distribution of the demographics is presented in Figure 7 for where the respondent works and Figure 8 for what role the respondent has. The respondents are 28 from TA, 24 from TB, 16 from TC and 4 from plant maintenance, as seen in Figure 7.

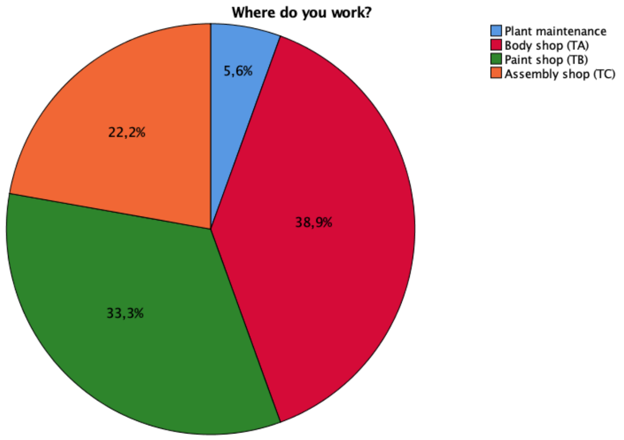

Figure 7. Distribution of which department or shop the respondents work in.

Respondents are 34 maintenance technicians, 20 maintenance engineers, 5 managers, 3 group managers, 2 planners, 4 preppers and 4 smart maintenance engineers, which is seen in Figure 8.

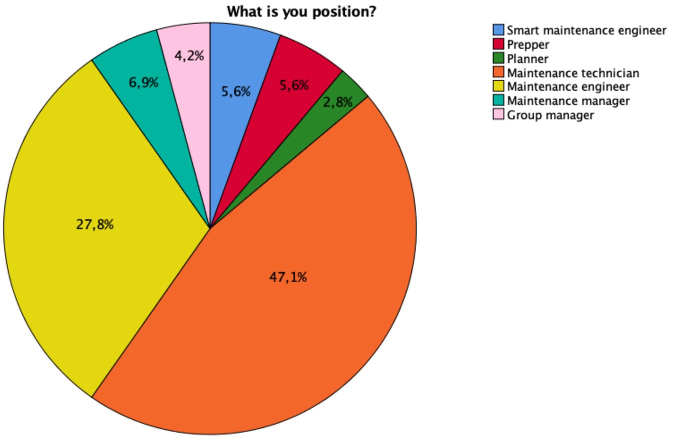

Figure 8. Distribution of the positions that the respondents have.

Majority of the respondents agreed with the statement that *Maintenance is planned in a fact-based approach*, where the mean of the answers is 3,6 but with an SD of 0,9. Answers between shops have small differences; TB has the most disagreeing or neutral answers of the shops while TC is the relatively most agreeing and strongly agreeing shop. The overall opinion is that maintenance is planned in a fact-based approach. In the statement *Predetermined processes and methods are followed in the daily maintenance work* the overall opinion is on the agreeing side with a mean of 3,6, however with a high deviation. Plant maintenance and TC is the most agreeing, TA and TB have more spread of answers. With a mean of 3,9 there is an overall agreement with the statement *Support systems are used within maintenance*. The answers are focused around the answering alternative *agree* and with spread around it. According to the results 45 of 72 respondents either agreed or strongly agreed that maintenance decisions are more based on experience than data, as presented in Figure 9.

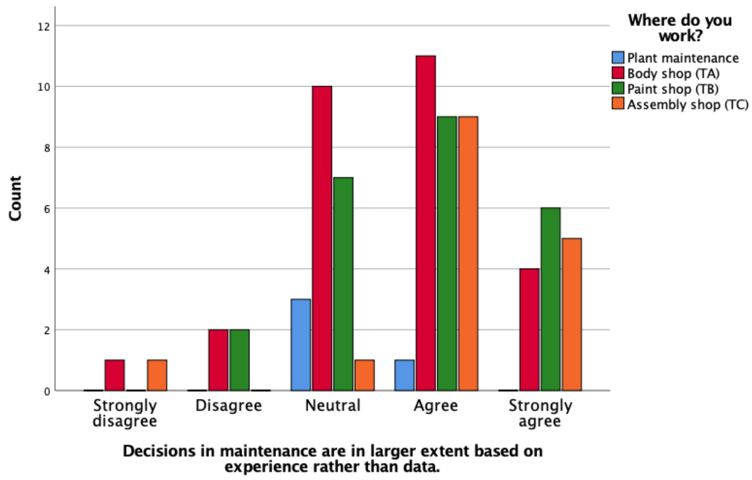

Figure 9. The answers to the statement to whether experience or fact is used for maintenance decisions, divided among shops.

With a high mean of 4,4 the respondents strongly agree or agree to the statement *Development of technology and new methods are important for good maintenance work*, which has the responses of 25 agrees and 40 strongly agrees. In general, there is a majority that agrees with the statement *You perceive that it is good with changes in work methods and processes*, but when comparing different roles it shows that technicians and engineers are most centered around agreeing while the other roles at strongly agree. In the statement *You trust in changes and development projects* there is an SD of 1,1 which indicates a spread of the answers. Further, the agreeing side has 37 respondents, while neutral and disagreeing have 35. In the statement *Data is used to conduct maintenance* the result indicates that there is a spread among the different answering alternatives, which is indicated by the SD at 1,3 and with the mean of 3,3. TC agrees to a larger extent than the other shops. While TA and TB have a more spread between disagreeing, neutral and agreeing. Seen in Figure 10 there is a spread in the level of trust to data-driven decisions. 40 respondents have trust in data-driven decisions, while 30 responded that they have a neutral or disagreeing attitude to the statement. Both TA and TC have more trust in data-driven decisions and TB has more answers in the neutral-disagreeing field.

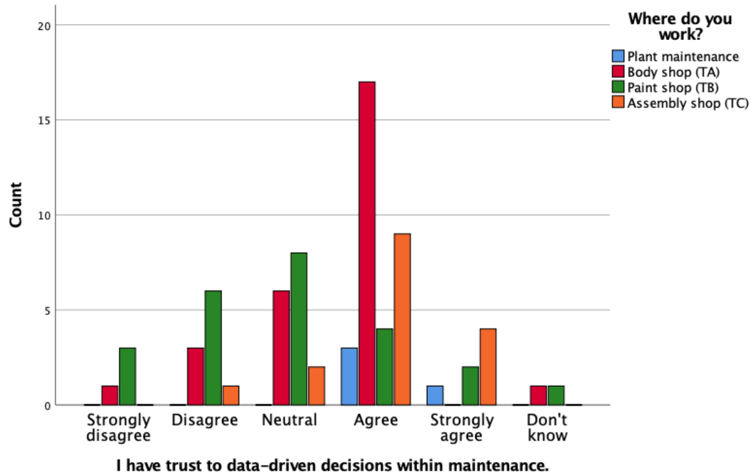

Figure 10. Distribution of the trust level to data-driven decisions between shops.

The response to the statement *Adequate amount of preconditions exist for working with data-driven decisions at VCT* is disagreeing and neutral with a mean of 2,9. However, there is a high distribution of the answers with a SD of 1,1. TC is overall more agreeing, while TA and TB have more neutral and disagreeing answers. For the statement *MES are used to support planning of maintenance* there is a widespread of answers with an SD of 1,1 and the response is neutral with the mean of 3,1. There is a strong agreeing consensus to the statement *Maximo is used in the daily work,* with 49 answers for strongly agree and 14 for agree. In the statement *KPIs and metrics are used to develop maintenance practices*, there is no consensus among any of the shops where the mean is 2,9 with an SD of 1,1. However, all smart maintenance engineers agree or strongly agree to a larger extent than the other roles. Further, there are 9 respondents that answered don't know to the statement. The respondents have an agreeing consensus that *VCT would benefit from taking more data-driven decisions within maintenance* with a mean of 3,8 and an SD of 0,9. There are 20 neutral answers, 28 agree and 14 strongly agree. Presented in Figure 11 there is a large number of technicians that either is neutral or don't know, while all other roles are more agreeing to the statement.

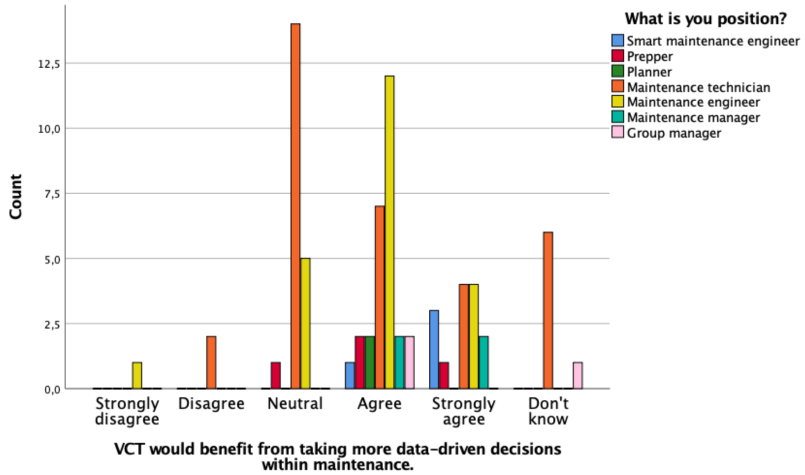

Figure 11. Distribution of answers if VCT would benefit from taking more data-driven decisions within maintenance.

There is a large spread of the answers to the statement *The maintenance organisation has sufficient amount of resources to perform their work* with a high SD of 1,2. The mean of the answers is 2,8 which is more neutral and disagreeing. Both TB and TC answered more neutral and disagreeing, and TA answered more agreeing. In general, the engineers answered that there is not sufficient resources while the technicians are more satisfied with the sufficiency of the resources. With an SD of 1,1 there is a spread of answers to the statement *There is adequate amount of staff to remedy all breakdowns in the factory* and the answers in general is neutral-agreeing with a mean of 3,2. TA agrees to a larger extent than the other shops. Moreover, the maintenance technicians are both neutral and agreeing in their answers, while most of the maintenance engineers either disagree or agree. In *Resources in maintenance is utilised efficiently* most answers are not agreeing to the statement with 28 in disagreeing and 11 in strongly disagreeing, where technicians are the group with most spread of answers with 12 in the agreeing side and 13 in the disagreeing side. TA is more disagreeing than the other shops to the statement *You have suitable education and experience to work more data-driven.* There is a majority of answers in agreeing with the statement, where the technicians both represent the largest part of answers for neutral and agreeing. There is a neutral response where the sum of answers is neither agreeing or disagreeing to the statement *Maintenance is a workplace that attracts new employees with good competences*, with a mean of 3,1 and a spread with the SD of 0,9. With 28 answers in agreement and 28 answers in disagreement there is a spread of the answers to the statement *Within the maintenance organisation there are sufficient resources for competence development,* further the overall answers is neutral with a mean of 3,0.

According to the answers to the statement *Prioritisations are made between maintenance activities where you work* all shops answered similarly. With 56 agreeing answers it indicates that all shops perform prioritisations between maintenance activities. The respondents believe that the right equipment is prioritised as 43 answered agreeingly to the statement *The right equipment is prioritised* and 8 answered disagree. 20 respondents answered neutral which results in that the mean is 3,6. Further, the respondents seem to have knowledge in which equipment is prioritised with a mean of answers in 3,7 to the statement *You have knowledge in which equipment that is prioritised.* Overall the prioritisations are followed with 41 answers agreeing to the statement *Predetermined prioritisations are followed*, however there is a group of 21 that is neutral to the statement. Most of the staff have knowledge in which equipment is the bottlenecks, with a mean of 3,9. Both TB and TC have good knowledge in their bottlenecks with a majority of answers in both agree and strongly agree. However, TA has wider distribution of answers with more disagreeing or neutral compared to the other shops, as seen in Figure 12.

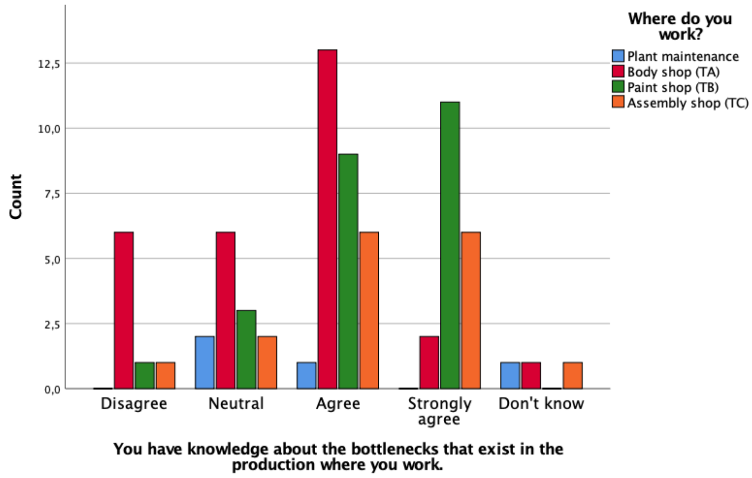

Figure 12. Distribution of the knowledge in existing bottlenecks, within the maintenance organisation.

All shops have a wide distribution in the answers to the statement *During breakdowns and longer stops the time is utilised to perform maintenance activities,* with an overall SD of 1,1. According to the distribution of answers, 30 respondents agree, 15 are neutral and 25 are disagreeing. Regarding the value in prioritisations, the majority of all respondents believe there is value in prioritising between work orders within RM, PM and improvement work, as presented in Table 5.

	Mean	**SD**
Reactive maintenance	4,1	0,9
Preventive maintenance	4,2	0,8
Improvement work	4,2	0,8

Table 5. Mean and standard deviation for statement 30, 31 and 32.

All roles except technicians responded to the statement *There is a good decision support which supports the maintenance work* and *The decision support for classifying critical machines in Maximo is used in planning of maintenance*. The distribution of respondents is 9 for TA, 12 for TB, 13 for TC and 4 from plant maintenance. With a mean of 3,0 the overall opinion is neutral regarding if there is good decision support for maintenance work. However, as seen in Figure 13 there is a spread of answers between disagree and agree. Plant maintenance is agreeing, and TC is neutral and agreeing, while both TA and TB are more disagreeing. The role that is mostly disagreeing is the maintenance engineers with 13 answers in the disagreeing field. There is a general disagreement to the statement *The decision support for classifying critical machines in Maximo is used in planning of maintenance,* with 9 strongly disagreeing, 13 disagreeing and 8 neutral answers, while only 4 agreed and 4 answered don’t know.

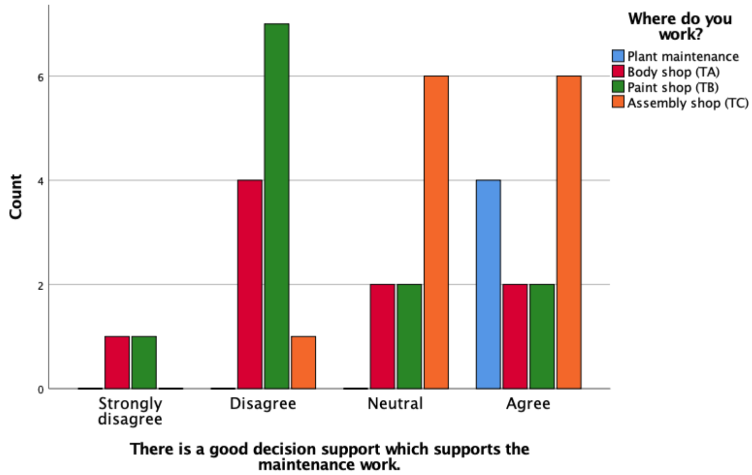

Figure 13. Distribution of the answers regarding if there is a good decision support which supports the maintenance work.

The statements *You have knowledge in the tool "active time" in the MES Axxos* and *The tool "active time" used to decision in maintenance* were only given to respondents in TA which further were not technicians. This results in a response rate of nine people. In the statements the respondents answered that there is a lack of knowledge in the tool and that it is not used for decisions in maintenance.

Key takeaways

In Table 6 the key takeaways from the result is presented, where the takeaways are presented connected to each researched topic.

Changes management	Participants perceive that development and technology is important for a good maintenance work
	There is a spread regarding trust in changes and development projects
Data-driven decisions	Respondents suggest that maintenance is managed with a fact-based approach
	Answers indicate that decisions are based on experience over data.
	There is difference in trust to data among the three shops
	Respondents think that VCT would benefit of taking more data-driven decisions within maintenance
	Maintenance technicians see less benefits to data-driven maintenance compared to other roles
Decision support systems	There is a consensus among the participants suggesting that support systems are used within maintenance
	No consensus in the sufficiency of support systems
	The applications for machine criticality and active bottleneck identification are not used
Demand	Participants suggest that resources are not utilised efficiently
	Answers indicate that is a lack in resources to perform the maintenance work
	A majority of the respondent's state that they see a value in prioritising between work orders within RM, PM and improvement work
	Lack of consensus regarding whether MOWs are exploited. Maintenance technicians agree to a larger extent than engineers.
Prioritisations	Most respondents think that the right equipment is prioritised
	The results show that prioritisations are made in the production
Resources & competences	Participants think there is suitable education for data-driven maintenance

Table 6. Key takeaways from the answers of the questionnaire.

5.2 Interview results

This subchapter presents the result from the interviews for RQ1 and the results are divided into predefined tags where answers in the specific topic is covered.

Maintenance & Organisation

The nature of maintenance at VCT is more reactive than proactive, which is something that the interviewees mention is on the path to shift. The shop which is the most reactive is TC where most focus is to remedy stops in the production. The technicians in TC are always on standby to clear up all problems in the shop as mentioned by an interviewee about stops "*... in broad terms you say that 1 minute [of stops] is a lost car.*", every second is important. An identified effect of the reactive mindset is that the organisation is too focused at solving the current problems that they do not notice opportunities for eliminating frequent recurring problems, which could be done through analysing Maximo data. In TA the situation is smoother as the shop has more capacity and also has buffers to cover up for disturbances in the production. Overall, TA is balanced but as one interviewee said, there is still improvement in the shop and more focus can be on being proactive. In TB the situation is also tight as mentioned by the one interviewee, the shop is a process which means that stops that occur will halt the whole line and stop production. The general opinion is that the staff in all shops manage all their stops within a reasonable amount of time. Regarding PM the staff thinks there is a need for improvement.In TC there are too many PM work orders than staff can manage, as maintenance technicians has to prioritise stops and have to cancel PM in the middle of the work. The result of this is that PM is but into a backlog, where work later on has to be crossed off without work orders not even being performed. In TA most of the preventive work orders are planned for the weekends, when the production use to be stopped. There has according to the interviewees been problems with overtime during the weekends that have put preventive work orders on hold and then put into a long backlog, as there has not been enough time to perform them. Additionally, a recurring problem existing in both TA and TC is that due to breakdowns during the week emergent repairs has to be prioritised for the weekends, which results regular PM work put in the backlog as well. During the weeks the maintenance in TA is mainly focused on RM as they are not allowed to enter the lines to perform PM, as going into the line stops the production. This is an issue mentioned by interviewees from all the shops, since there is not much PM that can be performed during operation hours as it disturbs the production. One interviewee said that by having time to perform the PM necessary the result will be that machines are will permanently break the equipment. Within TB it is mentioned that most work orders, both reactive and preventive are handled within a sufficient time. However, as the shop is a process the production cannot be shut down during weekends as in the other shops, which makes the TB resort to performing PM during holidays or special occasions with longer stops, where all possible PM activities are performed.

The PM scheduling is to a large extent based on recommendations from the suppliers of the equipment. The recommended schedule is checked by staff at VCT who uses their own experience to assess the schedule combined with communication with the suppliers. Thereafter, the schedules are set and added to Maximo which sends automatic work orders to the planning organisation when it is time for performing the maintenance. Mentioned as an issue with the scheduling is that there is too much trust to the suppliers' recommendations, as they might recommend shorter intervals when the equipment can withstand longer intervals between maintenance. However, one interviewee mentioned that there should be condition controls of equipment performed frequently to be able to adapt the scheduling of PM. Another issue mentioned with the scheduling of PM is that the intervals are based on weeks or days, rather than operating hours of the equipment. Moreover, there is little time during production hours to perform PM even during MOWs and even when MOWs appear the maintenance technicians are busy at fixing the breakdown rather than exploiting the time for PM. Additionally, during MOWs the organisation do not let technicians enter the line for PM as it is more important to let machines fill buffers. However, there is PM that could be performed as the planning organisation in TA plans more PM actions than could be done during the weeks if someone manages to take the time to perform any activities.

Within the maintenance organisation the interviewees mention that technical availability is the top KPI and all other performance indicators build towards it, the indicator is among other broken down into mean down time (MDT) and mean cycles before failure (MCBF). The interviewees mention that different roles in the organisation have different KPIs that they follow. One interviewee mentioned that KPIs are currently mainly used for just measuring performance, but that work is done to follow up KPIs and identifying trends. It was mentioned that in TB there is work to assign certain KPIs to roles in the organisation that can influence the indicators. Further, that managers are following up those indicators with the concerned staff.

Prioritisations

When there is more PM than what can be performed there are prioritisations between work orders during the planning phase.

In Maximo the it is possible to set the machine criticality for different work orders, either with regards to when setting the schedule for recurring PM or by individuals who request specific work orders. The machine criticality is graded on a scale 0 to 15 and is based on the experience & personal opinion of each requester. One interviewee regarded 5 to be something that is alright if not completed, 10 to be a critical work order but not urgent and 15 to be a work order that has to be addressed to avoid a breakdown. Moreover, it was mentioned that the grade is not always reliable as all individuals do not share the same view of what is critical or not. This bias is considered when prioritising between work orders. One interviewee said that the prioritisations between PM work orders are in the end done through a combination of the information in the work order and with their own experience. During the prioritisation the sensitivity of the equipment and localisation of the equipment is taken into consideration, from experience and insights of knowledgeable staff such as technicians and engineers. Considered equipment is those who pose harm, or equipment that easily breakdown or those localised in lines which are burdened with little spare capacity. Regarding prioritising right work orders one interviewee mentioned the workforce of engineers to be competent so when prioritising there is a general understanding of what is most critical. Additionally, one interviewee mentioned "*... maintenance is prioritised through experience I think, but that does not imply it is correct."* and that there is an uncertainty if prioritisations are correct.

Within TB, safety-related work orders are always prioritised, as there are many regulated processes in the shop. Thereafter, prioritisations are performed after single flows and equipment that is sensitive and could halt the production. In TC, RM is prioritised on the spot by the technicians, as one interviewee said equipment without backups are prioritised before screwdrivers as an example because they have backups. The interviewee also mentioned that the prioritisations between RM work orders are mainly performed by experience. In TA one interviewee said, "*If someone calls me I take my bicycle to that location, however if someone calls me while I am at the alarm I say; try the next person, I am on an alarm right now.".* The interviewee further commented that there is seldom need for prioritising between work orders and if necessary it is performed through experience of what is most critical.

Decision support systems

At VCT there is a general understanding that there is a need for working more with data within maintenance. However, it is mentioned that there is no certain strategy for how to reach such a goal. It is said in the interviews that people in the shops have great knowledge and experience in the machines, and it is suggested that sometimes it is better than the data. This opinion is however not shared by all interviewees. Further, according to the interviewees, decisions within maintenance are mostly based on experience rather than data. To which extent experience is used over data the interviewees are not sure of. There are great opportunities in working with data, as one of the interviewees said there is a possibility to follow up backgrounds for decisions "... *one of many advantages in working with data; it is easier to follow-up why certain decisions have been made."*, regardless whether the decisions were successful or not. It is also argued that without access to data, VCT would be in serious trouble. The interviewees also elaborate that to be able to work more data-driven, a prerequisite is to be able to interpret the data in a correct way. There is no value in having large amounts of data if the users cannot interpret and make use of the data.

Within the workforce there are many suggestions of applications that could increase the use of Maximo, as currently people create their own tools to fill the gap between what is needed and what applications are existing in Maximo. From a planner's point of view one improvement that could help is being able to list all competences that maintenance technicians possess as they today only can see their main competence, in order to be able to utilise the competences in the plant better. In addition to the current support, it is suggested that VCT would benefit from having a separate alarm system in TA, which could provide the maintenance engineers with information about current alarms. The decision support systems at VCT are used to a large extent, however according to the interviewees they are not fully optimised to suit their purpose. A big part of the workforce creates customised spreadsheets in Microsoft Excel to be able to analyse the data since there is seen to be a lack of support for analysing data in some of the systems. Regarding Maximo a pervading experience within the organisation especially among maintenance technicians is that Maximo is a tedious and time-consuming system to use. As one of the interviewees said "... *the system is unnecessary complex.*" about Maximo. Further, according to the interviewees due to the troubles in using Maximo, fewer maintenance jobs are reported, which affects the way future maintenance is planned, as stated "*Sometimes it takes more time to fill in the report than to execute the maintenance work.*". Due to the fact that Maximo is considered tedious to use, it is mentioned that the workforce would need more time scheduled to be in order to make thorough reports. Currently, due to lack of time, usually only the most crucial information is added, and often the reporting is missing out completely. Moreover, Maximo is considered to lack depth in the data which is mentioned to be an issue. Suggested by an interviewee if the system was to become more user-friendly it could improve the amount of reported work, which in turn would enable deeper analytics and follow-ups of maintenance by engineers.

The different shops at VCT use different MES. In TA, the MES Axxos is used. Where TB has the oldest system, which is a heavily modified system which is tailored to VCTs needs, however because the system is old the interviewees mention it is hard to use the system and to fetch necessary data. It is mentioned that Axxos is easier to use, allows easier access to data, and provides good analytic tools. However, according to the interviewees there are many issues with the Axxos and it needs several adjustments in order to work properly according to its purpose. There is a dedicated team working towards improving Axxos, but mentioned by the interviewees there is a lot of work to be done and the team needs more resources to be able to finish the work.

Data-driven decisions

There are both constraints and opportunities of working with data-driven decisions in maintenance. According to the interviewees, there are two fundamentals for working with a data-driven approach; access to data of sufficient quality and support systems in which the data can be analysed and visualised. VCT currently have support systems to analyse and visualise data, however, the interviewees state that there are problems with the in-data to the systems. The users of the systems argue the accuracy of the in-data to the support system often is insufficient and in those cases that is does not help if the system has good applications. Accordingly, if the in-data is of insufficient quality, the quality of the output from the system will be insufficient for making successful decisions. However, the general perception is that data-driven decisions within maintenance will improve the quality of the decisions, but the interviewees emphasise the importance of using data of high quality.

A commonly mentioned constraint for working with a more data-driven approach is the insufficient support systems and the lack of use in the systems. Explained by the interviewees the lack of use in the systems have many reasons and trust is one of them. According to the interviewees the interest and trust in working more data-driven is split between different generations among the staff. The new younger generation of employees have a positive mindset and are eager to work in a more data-driven approach, while there is some resistance in working with data among the older generation of employees. A contributing factor to why there might be some resistance among older people is due to the vast experience of the older employees, and the "*... some people have been working for such a long time that their experience almost gets fact-based.*". Currently a large part of the maintenance work is based on the experience of the people working in the shops. Moreover, since VCT rely on experience in a large extent, it creates a vulnerability for a future competence gap when the older generation of employees retire. One interviewee mentioned that data could be incorporated in the maintenance work in a larger extent to prevent a future competence gap. Further, since the older generation possesses such a large competence, one interviewee mentioned that when someone points out trends in data it is hard to get them aboard as the older employees easily can discard the data to be false. In order to work with a more data-driven approach, there is according to the interviewees an obvious need to increase the understanding of how to interpret the available data. Not seldom, maintenance engineers need to explain and convince the maintenance technicians of the benefits of the data, as well as how to interpret it. However, a factor that is affecting the trust of maintenance technicians is that they often experience errors in the data. Moreover, regarding competence development in data-driven maintenance some interviewees mention there is a need for developing the knowledge in the workforce. Moreover, as one interviewee said, "*There is a lot of competence within VCT, even though each person does not possess all competence.*", and that there is a lot of competence sharing internally between different roles. According to the interviewees there is a lack of opportunities to learn more about the support systems, and often each individual has by themselves request necessary competence development.

According to the interviewees, one of the major constraints for working more data-driven is the level of trust in data, especially to Axxos. The mentioned factor that affects trust the most is errors in the in-data to the systems, which according to the interviewees has to be fixed in order to increase the trust. There is a split view regarding the level of trust between different roles and individuals. From the technician's perspective the trust was lower due to their experience that data often has errors in them, while technicians believed in the data more but that to use it with caution. Additionally, there is a different level of trust among the shops, according to the interviewees an explanation to the difference between shops could be the fact that they all use different MESs. In the MES in TC there is a function of resetting alarms, which according to one interviewee makes it possible to test if the alarms are false or real. The function in turn makes it possible to sort away noise in the data in the MES which makes it easier to see the important things. While in TA the interviewees mentioned there are currently many doubts in the Axxos data and it affects the use of the system. One interviewee mentioned that the data cannot be trusted for analyses by itself as the data is not accurate enough, but it can be used for comparative applications and for tracking trends. Another interviewee mentioned that the data is sufficient for basing current decisions on but that there is still improvement to be done. Moreover, the interviewees argue that there are several improvement areas that can be filled to enhance the use and trust in data-driven decisions within maintenance. A mentioned example for increasing trust is to improve DQ, where as an example more maintenance work has to be correctly declared in Maximo. In order to achieve this, the maintenance technicians have to be provided with better prerequisites, such as time to correctly report the work orders and further education in how to fill it in correctly. Mentioned problems caused by insufficient amount of reported work orders in Maximo is that it is difficult for engineers to judge whether the PM schedules are needed, as there is a lack of feedback reported of previous PM rounds. Another mentioned problem is that for technicians working four shifts that sometimes they do condition checks on machines but there are never any issues with the machines, while another technician that has another shift always gets the problems during their shifts. This makes some technicians suspicious to data as they never notice problems themselves. Some interviewees suggest that the maintenance organisation needs additional competences regarding IT and databases. Lastly, there is a need for improvements within the support systems regarding visualisation of data, to avoid the need for personalised tools. There are resources for competence development, however the interviewees are ambivalent in whether there are enough resources to cover future need on increased knowledge in data.

Development & Change

In general, the interviewees have a positive attitude to change with a mindset that current practices can be improved. The interviewees mention however that there could be a mixed opinion among the workforce in the shops. It was mentioned in several shops that there could be an overall feeling of skepticism towards changes and that staff is probably less inclined to changes, however one interviewee said that skepticism is not always negative and that there are benefits with some resistance. Regarding changes one interviewee said they are welcomed if they have thorough planning and thought process behind it, while being less inclined towards overhasty changes. Several interviewees mentioned that the attitude to change might depend on the age group and profession. One profession that is less prone to changes were mentioned to be technicians, this was explained by that technicians are a profession where people tend to have long careers within and thus they take a lot of pride in their work. Further, this pride makes the technicians cautious to changes as they tend to have a deep experience in their field. From the technician point of view, it was mentioned that in some development projects the management and project leaders are misinformed about reality. The interviewee said that due to the misinformation there where people trying to push a change that would affect the organisation negatively, this was mentioned as a reason for skepticism towards development and change. Further, it was mentioned that some resistance to some development projects exist because it feels that the top management is mainly looking at the number of development projects rather than at the benefits of them.

To motivate the organisation in development projects or changes one interviewee mentioned it was important to communicate the benefits and to show how the change really affects the organisation. One interviewee said that the staff has to understand in order to increase the willingness to push and adapt to the change. During the interviews it was said that the younger generation is more adaptable as they see more benefits with the change. While the older generation is more cautious as they want to fully discover the benefits before committing to the change. Additionally, it was mentioned that the older generation might have a higher threshold for adapting to the changes. One interviewee said that the engineers have a high drive for change as developments are a natural part of their daily work. Generally mentioned about changes at VCT is that people tend to want to develop their own work but that there is a problem with people losing interest in driving the change. As development projects often extend over a long period of time people do not see any change happening they lose interest as they do not see any result in their work, thus one becomes dissatisfied with the development.

Key takeaways

Presented in Table 7 the key takeaways from the interviews are listed in the predetermined tags that the information belongs to.

Maintenance & organisation	VCT is to its approach more reactive than proactive in maintenance
	The amount of PM is more than could be managed
	PM interval scheduling is mostly based of experience and supplier data
	MOWs cannot be exploited
	The maintenance organisation is focused around the KPI technical availability
Prioritisations	The machine criticality and work order criticality grading is based of experience, and is not considered reliable
	PM is based on experience of maintenance technicians, engineers and planners
	RM prioritisations are made by experience of maintenance technicians
	Prioritisations are made after sensitive equipment and bottlenecks
Decision support systems	Most of the interviewees think that Maximo is tedious and time consuming to use
	Data is important for decisions at VCT, but the organisation think more data-driven decisions has to be taken
	Employees create their own tools to cover for the lack of support in the support systems
Data-driven decisions	There is a lack of data and DQ in Maximo
	Accuracy of the in-data to the support system is often insufficient
	There is lack of consensus regarding trust to data
	Errors in the data affect the trust to data by technicians
	Lack of trust to data in Axxos
	Staff uses experience to cover up for lack in DQ
	Due to lack of awareness and knowledge in the application *Active Time,* it is not used for prioritising maintenance
Development & change	Top management focus on the quantity of improvement projects rather then the quality
	Changes are long processes and people lose commitment due to not seeing change
	There are different views of trust to changes, mostly positive
	No consensus regarding if there are sufficient resources for competence development

Table 7. Key takeaways from the answers of the interviews.

6. RESULTS OF RQ2

This chapter presents the results of the subjective assessment and objective assessment.

6.1 Subjective assessment

The interviews were held with three different people, one from IT, one specialist on Axxos and one user of Axxos. The person from IT and the specialist on Axxos contribute with the provider view of the data, while the user contributes with the user's view. This subchapter summarises their experiences and knowledge about DQ in Axxos and related areas.

Users come in contact with Axxos in two ways, either by sending manually coded alarms to the system through the HMIs available at the production lines or by using it to analyse & visualise data. The purpose of sending manually coded alarms is to provide missing data of alarms and errors that occurred in the work station. The system is used in TA at VCT and at other VCC sites. The data is accessed in the interface of Axxos and shows a real-time view of the production system. According to the interviewees there is a problem with coding of alarms, where alarms are not coded in time or that coding lacks sufficient information. The interviewees regard the trustworthiness of the data to be high and probably in most applications the data is sufficient. One interviewee said "*... it's more towards 99%, but if that is enough? That is hard for me to tell.*" about the level of trust to the data. It was mentioned that users in the organisation might not share the same level of trust as the providers of the data, but the overall trust is good. To be able to take good decisions and to take the deviation of data into consideration when performing analyses, one interviewee mentioned it is crucial to have experience of reality to fully be able to understand if data represents it.

The interviewees mention the level of DQ is both low and high, where they mostly agree that it is good, as one interviewee said about the DQ "... *currently it satisfies my needs.".* It was however mentioned that there is always room for improvements as there in some occasions are problems with the indata to Axxos, which in turn affects the accuracy of decisions based on the data. The mentioned problems that are easy detectable is when data is missing or when cycle times have negative values. What is further mentioned is that there are problems with false alarms that do not stop being active, even if the alarm is relieved. When false alarms stay active in the system other alarms cannot be displayed and the data do not reflect the reality. The alarms do not affect the production, but they affect what is seen in the data. Mentioned by the interviewees is that as a result of false alarms the data is distorted and that other serious alarms might not be seen on the alarm top lists. Regarding the accuracy of the in-data, one interviewee said "... *there are still parts of the system where the data is not imported accurately, however, it is hard to say how big the problem is."*. The interviewees acknowledge that DQ problems exist, but that they rarely are identified. Some problems with the DQ are hard to fix as they are rooted in the PLCs where data arrive from robots, sensors and other components. Further, in some rare situations it has occurred that external factors have influenced the DQ negatively when the PLCs are reset, such as when contractors perform updates on the hardware.

Both the provider and users consider the data format to be easy to understand and to work with. The user mentioned that the data is well managed and presented in the interface of

Axxos and that there is also an easy way to for export the data to an organised spreadsheet, which enables the user to work directly with the data. The data that serves as an input to Axxos arrives in a standard format, which means that system does not have to process any format of the data before using it. The software Virtual Device (VD) transforms raw data from the PLCs into a standard format and acts as an intermediate layer between the PLCs and Axxos. The advantage of VD is described as "*... VD is an intermediate layer that among other things does that Axxos don't have to know what types of PLCs there are here. And, if someone changes a PLC to another one, then they don't have to be bothered about it in Axxos as it's administered in another layer…*". Mentioned by the interviewees, the main issues when transforming the format is that alarms are complex, and problems might occur, while the cycle times are easy to transform. In general, the processing time of the data is sufficient as it there is only some seconds delay between Axxos and reality, which means the system provides real-time updates to the users. Further, users can get customised reports from the system, but with a couple of hours delay for the analysis. The delay for the analyses is about four to six hours, but according to one interviewee in theory the reports and analyses could be updated with higher frequencies.

There are two levels of quality assurance and support for Axxos, the first level is between shop level with the specialist for the system and then the second level is between the local specialist and the corporate IT organisation. Most problems are handled by the local specialist but with more difficult problems support is given by IT organisation. If the IT organisation cannot manage the quality issue the system supplier is consulted. In cases where the problem lies in the in-data, the quality issue is handled by local PLC experts at VCT in collaboration with staff in the operations. According to the interviewees IT has a responsibility for supporting the organisation when issues occur. It is further mentioned that IT does not have any formal responsibility for proactive quality assurance of the data, but in some occasions encounters issues in the data while performing other work and then flags it. The responsibility for proactive quality assurance lies at the local level, which is led by the Axxos specialist. The proactive quality assurance is performed by a systematic approach with weekly meetings, for identifying issues with Axxos regarding both the system and its data. Participants in the meetings are production staff, maintenance staff and the local Axxos specialist. Additionally, the local specialist is working with validating line by line that the data is correct and that DQ is sufficient for the organisation. The work aims to assure the consistency between data and reality. Further, the local Axxos specialist is monitoring the DQ continuously by verifying random samples of the data. One interviewee mentioned that for detecting problems there is a joint responsibility "... everyone is working together with it and as I go through the system I might see some errors and then I flag for it…". However, it is important for the staff in the organisation to report errors as they can detect anomalies in the data, as one interviewee said "*... the greater part lies in the maintenance technicians and the teams who work with it, they are the expert on it.*". Mentioned by the respondents, the IT organisation and the specialist can only detect some issues in the DQ by themselves, as they have limited knowledge of what the data should represent.

In the interviews it was mentioned that there might be a missing interaction in quality assurance among the IT organisation and local specialists. What was mentioned was a lack of systematic work for improvements in increasing the DQ within Axxos. Additionally, the specialist in Axxos suggests that there is a need for educating the users of the system as the person mentioned "... e*ver since Axxos has been proven to be more useful for the teams of* *engineers, the interest within the organisation has increased.*". With an increased interest generated by more education the awareness of DQ is improved, which leads to more reported quality issues.

It was acknowledged by an interviewee that in a future scenario, where decisions are based on real-time data there could be a need to assure the DQ to a larger extent. The interviewee mentioned that the DQ is sufficient for current applications but for more active decisions with shorter time frames DQ might be an issue. Suggested approach for assuring the data would be by collaborating between departments in workshops for a larger overhaul of the DQ. Another step deemed necessary by another interviewee is to perform validation of the correctness of the tools used in Axxos, as it has been noticed in an earlier case that a tool had bugs which led to errors in the results of the tools. In that case the system provider was involved in order to solve the specific problem. The interviewee mentioned that this could be done with other tools of interest as well. In addition, as the answer whether if such a tool, the bottleneck identification tool *active time* is used, the interviewees were not sure. Some had seen it but not used it in recent time, while another interviewee mentioned that the organisation has not fully grasped how the tool works. However, one interviewee mentioned that if the tool were to be used to a large extent, it is recommended to validate the results of the tool.

Key takeaways

In Table 8 the key takeaways of the interviews are presented combined with the according tag.

Data format	Both the provider and users consider the data format to be easy to understand and to work with
Data quality	Lack of consensus regarding the level of DQ, but in overall the DQ is considered good
	There are problems with false alarms which distorts the reliability of the data
	Hard to identify the level of DQ problems from the providing perspective
Quality assurance	The work for proactive data quality assurance is led by the local Axxos specialist
	The proactive quality assurance is performed by a systematic approach with weekly meetings, for identifying issues with Axxos regarding both the system and its data
Quality improvement	It is considered that there has to be an overhaul of the DQ to work more actively with the data
	Validation of *Active Time* is suggested to be done before more extensive use of the tool
Data speed	The users can get real time updates of the production system
Trust level	No consensus in trust to data among users and provider of the data
Other	The tool Active Time is not used by the interviewees

Table 8. Key takeaways from the answers of the subjective assessment.

6.2 Objective assessment

The objective assessment was performed by firstly comparing in-data from Axxos to data from VD both through checking accuracy between the datasets but also through checking consistency overtime. Thereafter, the data was assessed through comparing it to the DQ indicators. The data assessed was both alarm-data and cycle times, where the data came from one line at TA from a timespan of one month. The datasets were organised in spreadsheets for the assessment and comparative reasons, while in normal circumstances the data is only accessed from the interface in Axxos.

The first assessment was performed by comparing the cycle times in VD to cycle times in Axxos through time. In addition, the product ID for the processed car was also compared. The cycle times and the product IDs were compared between two spreadsheets where a formula tested if timestamps, cycle times and product IDs correspond between the two datasets. In 220 samples there was one sample that did not match between Axxos and VD. The sample that did not match between VD and Axxos was caused because of an additional timestamp that was existing in the Axxos data but not in VD. The timestamp in the Axxos data indicated that there was a stop at the current station at the timestamp. In the following data all other data corresponded as well. The cycle times were further tested by checking if there were any negative or abnormally high values. Identified were some values outside a normal interval such as -2147483 seconds and 2147483 seconds, these values are identified as anomalies in the data. The cycle times are organised in a clear and understandable structure, which enables to detect deviations and discrepancies in the data. The data format is consistent and follows the set standard.

The tests of the alarms were made in 10 samples and the testing was performed manually. These tests were performed by comparing alarms codes in Axxos to those in VD to see if the data is transformed correctly. The samples were taken with a spacing between time in order to also identify discrepancies over times. The compared data implicated severity, machine ID and the timestamp. All 10 samples were correctly compared, and no discrepancies were found between the data sets. The data was presented in a standardised format and the samples followed this format.

7 DATA INTERPRETATION

The chapter is divided into three analyses one each for pre-study, RQ1 and RQ2.

7.1 Pre-study

There is an overall need for prioritisations in RM, but in TC it seems to be the highest and in TA it is lower. In general, breakdowns seem to be managed. Prioritisations of PM seem to be performed based on experience by the planner as the criticality grading does not seem to be used, this needs further exploration. The tool for identifying bottlenecks *Active time* seems not to be used, which needs to be explored as to identify whether this is accurate for all of TA or not.

7.2 Analysis of RQ1

The analysis is divided into one analysis for the questionnaire, one analysis for the interviews and one combined analysis for the overall result of the research question.

7.2.1 Analysis of questionnaire

There is a doubt if there are sufficient amount of resources to perform the maintenance work in the factory, where TA seems to have more resources than the other shops. Which could correlate to answers if there is sufficient amount of staff to remedy breakdowns, where TA seems to be the most positive shop. However, in overall the resources that are lacking in the maintenance work is not primarily to do with the amount of staff as the general opinion is that the level of staff is sufficient. Despite the opinion that there is enough staff to remedy all stops, the answers point out that the resources are not utilised efficiently. The lack of resources and its efficiency imply that there is a need to utilise resources in a better way. Regarding how resources are used, the maintenance organisation prioritises between maintenance work orders where the general opinion is that the right prioritisations are made. However, in comparison to how well resources are utilised it seems that the prioritisations are not enough to make the organisation think the resources are utilised efficiently. On the other hand, there is a strong belief that there is a value in prioritising between work orders in RM, PM and improvement actions in maintenance. In addition, a majority of the respondents believe there is value in prioritising maintenance to bottleneck equipment. Another way to efficiently utilise resources is to take advantage of MOWs during breakdowns, however there is an ambivalence regarding if it is utilised, where TA seems to take slightly better advantage.

There is a lack of consensus with both negative and positive opinions regarding if decision support is sufficient for current work. Both TA and TB are groups which are less satisfied with the support, where maintenance engineers are a prevalent group which is not satisfied. Even though there is a dissatisfaction to the support systems a majority of the staff believes that predetermined tools are followed, where both Maximo and the MESs are used in the daily work. However, there could still be a problem with support not being sufficient but there are no alternatives of support for the staff. There is a need for further investigation in how the staff’s opinion about the systems affect the usage of them, in addition if it affects the trust of the data in the systems and the decisions taken of that data. Additionally, regarding decision support, as a large majority of respondents think there is value in prioritising maintenance to bottleneck equipment it is noteworthy that there also is a majority that responded that they do not know about the bottleneck identification tool *active time* in Axxos. If there currently are prioritisations to bottlenecks it is remarkable if the existing decision support is not used. Further, there could be a correlation between people not being satisfied in current decision support with that they are not fully aware of the existing support tools. Lastly, the tool for machine criticality in Maximo for planning PM seems not to be used which could resort to the staff in using other unidentified approaches.

There are contradicting results from the questionnaire regarding how maintenance is planned and what it is based on. The opinions are that experience triumphs data in maintenance decisions, however it is considered that maintenance is planned based on fact. The contradiction could be explained if respondents use fact to plan maintenance but in the end the experience is the deciding factor, however this needs further explanation. That experience triumphs data could have a connection to that approximately half of the respondents are doubting in their trust to data. The level of trust could be related to the ambiguity if adequate preconditions exist to work with data-driven decisions at VCT, contributing factor but not the single one might be that two fifths do not believe they have suitable education for data-driven decisions. If education is a factor, more resources could be needed for competence development as there is a lack of consensus regarding the sufficiency of the resources available. Despite experience triumphs data the opinion is that data is used for maintenance work, where TC is the shop that uses more data. There is a need to investigate what factors that affect the trust of data and if the trust affects the use of data. The trust and use of data do however not seem to affect the belief in the value of data-driven decisions, as the overall opinion is that there is value. Different roles seem to have different views of the value, where technicians are more neutral than other roles towards the benefits of data-driven decisions. Moreover, there is an uncertainty if KPIs are used for developing the maintenance work at VCT, which is remarkable as it is an important data-driven tool for controlling organisations progress.

The general belief in staff is that it is important to develop maintenance practices and technology in order to perform a good work and that the changes are good, but at the same time the level of trust to the implementation of the changes are less than the perceived value. The highest trust to changes is found in TC, while the other groups have slightly less trust. There is a need to explain why staff believes there are benefits of changes and developments, while not trusting implementation of changes to the same extent.

7.2.2 Analysis of interview

The overall demand at VCT is to prioritise between maintenance work orders in both RM and PM, where there the highest need for prioritisations are in PM. However, during production hours RM dominates prior to PM, due to that the factory cannot stand still. There are different needs in the shops due to differences in processes and spare capacity, which affects the need for prioritisations RM. Whereas in TA the RM is prioritised according to FIFO, which is possible due to less breakdowns and the many buffers that reduce the effect of production disturbances. In TB, RM is prioritised due to smaller margins and high need for safety, which results in prioritisations being on sensitive equipment that could stop the process or safety critical equipment. In TC on the other hand, there is an even higher need for prioritising RM, where the most production critical equipment is prioritised for the up-time of the production system. Even though RM prioritisations are important for the VCT they are based ad-hoc generally on experience of maintenance technicians, this is noteworthy as experience might vary among technicians which could mean that different equipment is prioritised.

The organisation in each shop has a hard time coping with the existing amount of PM work orders, which could be due to the number of emergent repairs, that MOWs cannot be exploited, that PM intervals are not optimal and due to the high production pace. Emergent repairs and part changes are not avoidable, but they create a problem where they exploit the resources that could be put in PM activities. Moreover, the production runs on a high capacity and often on overtime, which further contributes to the issue that there is a lack of time for performing PM. In addition, as of the high demand there is less time to stop equipment from processing during operating hours to perform PM, even when there is soon blockage or starvation ahead. The situation makes the staff unable to exploit emerging MOWs, as the mindset is to run the production as much as possible even if PM in theory could be done in an appearing time slot. Moreover, there seems to be a lack of support in both the organisations and in decision support to fully exploit MOWs, which is noteworthy as performing PM during MOWs could help in coping with all PM. Lastly, as PM intervals are heavily influenced on supplier data which could be biased and by experience of planners which could be wrong, there could be a problem that the intervals are not set in optimal frequency which could be a reason there is too much PM to be performed.

The problem with PM being down prioritised in favor of other activities is that it is put in a long backlog, this could have serious effects as equipment might suffer long-term damages which could imply longer breakdowns in the future. The situation creates a need to perform the most necessary PM, which could be achieved by prioritising in the best way and to reduce unnecessary PM activities. Additionally, to be able to perform more PM which could be done by exploiting MOWs. To enable this, there could be a need to provide better support to take full advantage of MOWs, both support within the organisation and in form of decisions support tools. Moreover, there could be a need to become better at reviewing the set PM intervals and by adjusting them after condition controls, in order for more optimal intervals. In addition, there could be a need to provide more support to be able to set the optimal PM intervals. For prioritising there is a need for providing support to making the right prioritisations as to the largest extent perform the most necessary PM.

The decision support for PM is insufficient which makes planners resort to experience instead. The existing support with a work order criticality grading cannot fully be trusted as there seems to be a mixed view of how to set the grading. The main problem identified with the grading is that requesters of PM might lack holistic view and the relative importance of the work order, which result in the grading being based on requesters experience and opinion. Further, there is a vulnerability if the planner does not have adequate experience of what is critical to prioritise which could result in wrong PM being prioritised or that misused grading of certain interests slip through. In addition, there is could be a problem with that there is a lack of procedures for following up whether right equipment is prioritised or not. Regarding what is taken into opinion when prioritising PM, bottleneck lines or equipment are a priority, as well as sensitive equipment that is likely to cause a breakdown. There is however no indication of how this equipment is identified beyond experience of planners and staff they consult. The lack of support, use of experience and lack of follow up in prioritisations could be factors for a risk that wrong equipment is prioritised. Moreover, there is support for following up if maintenance is prioritised correctly, which is through the KPI technical availability. However, it seems that KPIs are mainly used for measurement than taking corrective actions after. Further, technical availability might not show improvements when prioritising after bottlenecks, which could be identified in the KPI of productivity which is not followed in the maintenance organisation.

Despite that decision support systems are used to a large extent the systems do not fully provide the sufficient support to the users, which resorts staff to create their own tools to analyse and visualise data in the desired way. This creates a situation where all people do not use the same tools which could entail that different individuals and roles have different prerequisites to work with data. The implication of the lack of desired support could be that there is a higher dissatisfaction in the support systems. Regarding Maximo there is wide dissatisfaction in the system, this could be explained by that the system is tedious to use and is considered user-unfriendly. As it at times takes more time to report work in Maximo than it takes to perform it, there are problems with a lack of reported data in the system. Which in turn creates an issue with insufficient information to support follow up on maintenance in the shops. Further, this creates an additional issue with the given support as the data does not fully represent reality and could affect the quality of decisions taken of it, which in turn could affect the satisfaction of Maximo as well as trust of the data. In extension this could result that engineers have a hard time to use Maximo data to optimise the PM intervals.

The differences of satisfaction to the MES between the shops have many explanations, where the two most prevalent are the DQ and user-friendliness of the systems. The dissatisfaction found in TB can be explained that the MES is old, which requires more effort to access relevant data compared to the other shops. TA on the other hand has a more modern MES with greater support to access data, but due to insufficient DQ there is a dissatisfaction and lack of trust to the system. The DQ also affects the trust on data and the decisions taken by it. However, it seems that the dissatisfaction lies in the DQ of in-data rather than the system itself, but staff have a hard time seeing the difference. Furthermore, in TC there seems to be a higher satisfaction with the MES as it seems that DQ is higher, which could have an explanation in that false alarms can be canceled in TC and thus not affect the DQ as much. One suggestion to increase the support in the MES Axxos, is to create an application the informs and visualises alarms in TA to enable more efficient RM, which could also increase the satisfaction with the system.

Data seems to be of great importance for VCT and the maintenance organisation is heavily relying on data in their daily operations, even though decisions are very experience-dependant. The perception is that there is value with data-driven decisions, however there are different opinions to which extent data should be used and could be trusted. The correlation that could be identified is that people who work more with data are those who are more positive towards data. Two crucial factors for taking good data-driven decisions in maintenance seem to be having good support systems and accurate data. The factors are closely related as insufficient DQ also affects how good the support is from support systems, as the decisions are only as good as the data it is based on. Moreover, as there are flaws in the DQ it is common among staff to compensate with experience to take the deviation of accuracy into consideration when taking data-driven decisions. Further, for Axxos some state that the data is used more as an identifier for tracking trends rather than something that could truly represent the current state. The approach of using experience to cover for data and only use data as an indicator, implies that there are issues about the DQ at VCT, but it is hard to determine to which extent it affects data-driven decisions. What should not be forgotten is that actions are taken to improve the DQ at VCT especially for Axxos in TA. There is however a lack of consensus regarding if there are enough resources for this, where staff closer to the daily operations are less positive about the progress of changes.

The lack of DQ is not confined to the MESs, there also seem to exist similar problems with Maximo data. The explanation for the DQ issues in Maximo is mainly due to the lack of or insufficiency in declared work in the system, which in turn creates issues in quality of decisions taken of Maximo data. Moreover, this could also be a reason why many think experience is more important in decision than data, as the lack of data and its quality make decision makers rely more on experience to cover up for the data. Further, as a result of the lack of DQ there are trust issues towards the data. Explanation that there are different views regarding the trust to data it is usual for technicians to identify cases where data is not accurate and do not align with reality, this regards to all types of data. In addition, there are differences among generations regarding the trust to data, where it is identified that younger staff seem to be more prone to work with data while the older generation seems to be more hesitant. An explanation could be that younger people have an easier transit to working with data, while the older generation rather relies on their long experience. The different trusts create a misalignment in the organisation where there could be a problem where some people rather resort to experience instead of using the data, which could harm the extent data is used in overall in the organisation. VCT seems to need stronger communication regarding the benefits of working more with data in order to convince the workforce to become more data-driven. In addition, to increase the use of the systems, it is mentioned that more scheduled time for reporting and analysing data is needed.

The perception is that developments and changes have positive effects on the maintenance, but there are doubts to the implementations of them. Two important things for the doubts are identified, firstly that changes are lengthy processes and secondly that top management seems to chase number of developments rather than results. The explanation of the lengthy processes is bureaucracy, which makes people lose interest due to not seeing changes. The perceived view of the top management's attitude on developments makes people lose their own drive for changes as they feel that management is looking for quantity over quality. Additionally, an approach that was identified to be important for the staff was communication of the benefits of the change in order to accept the changes. Within the staff there are different opinions of change, where most groups are prone to changes but that technicians are more cautious. The cautiousness is explained by maintenance technicians' pride towards their professions which make them a bit hesitant towards others that want to change their way of working.

Education is one way to increase the use of data-driven support systems, which could have additional benefits in increasing both the trust in the systems and its data. There are different views about resources for competence developments, which can be explained by that there is a lot of resources in law enforced educations but not as much in other types of education. Outside these educations it seems that competence development mostly is internal learning between colleagues. In general, it seems that competence development mostly is performed after the realisation of each individual rather than systematically by the organisation. Which could explain that some staff do not have enough education in some support systems and other data-driven tools. By promoting more education towards the staff, it could also increase knowledge in data and the support systems, which could increase the amount of data-driven decisions and trust towards data.

7.2.3 Combined analysis

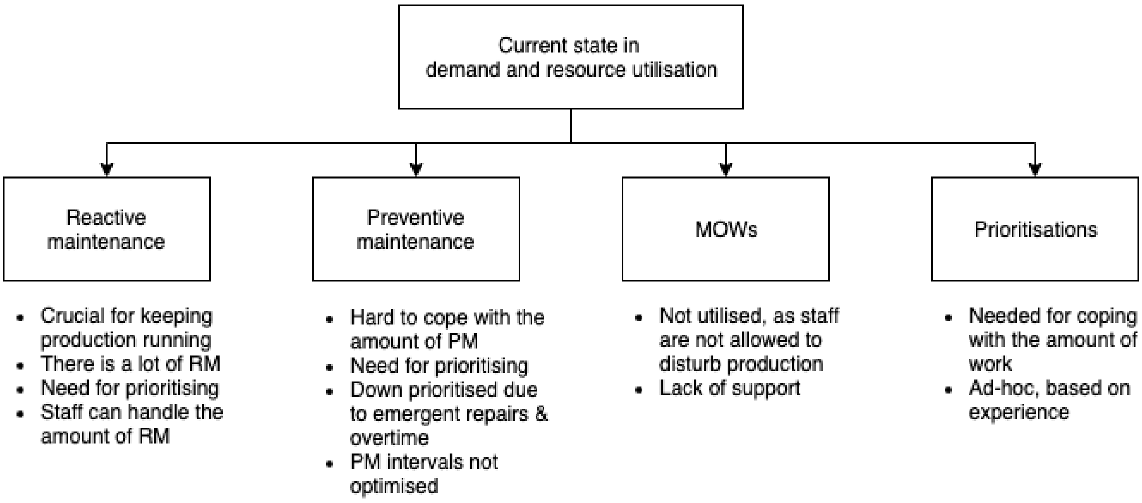

Figure 14. The current state in demand and resource utilisation in the maintenance organisation at VCT.

Identified are four areas in demand and resources in the maintenance organisation that are prerequisites for becoming a more data-driven organisation. The areas are *Reactive maintenance, Preventive maintenance, MOWs* and *Prioritisations*, as seen in Figure 14. There is an apparent need for prioritising the current resources more efficiently as there is a doubt if there are enough resources and if they are utilised efficiently. In general, it seems that there is more work than what could be managed and that there is always a need for work emerging. The area where this affects mostly is in PM where emergent part changes make that PM has to be prioritised. However, both interview and questionnaire data point out that there is enough staff to remedy breakdowns, but there is still much RM do be performed and sometimes there is a need to prioritise the RM. The questionnaire and interviews support each other in these questions and in overall it points out there is value in prioritisation between work orders in RM, PM and improvement actions in order to cope with the situation. Regarding if the right equipment is prioritised, the answers differ between the questionnaire and the interviews. The answers in the questionnaire suggest that the right equipment is prioritised, while the interviewees suggest that it is hard to judge and that there is a risk that the right equipment might not be prioritised. It is also suggested in both the questionnaire and interviews that there is value in prioritising bottlenecks, which correlates to that they do prioritise bottlenecks and sensitive equipment. Regarding the performing of maintenance during breakdowns and longer stops there is an ambivalence. During scheduled stops there are maintenance performed but it seems that there is a lack of support in the organisation to exploit MOWs that emerge during unplanned stops, which could explain the two different views from the questionnaire and the interviews. Lastly, due to the lack of organisational support MOWs cannot be exploited.

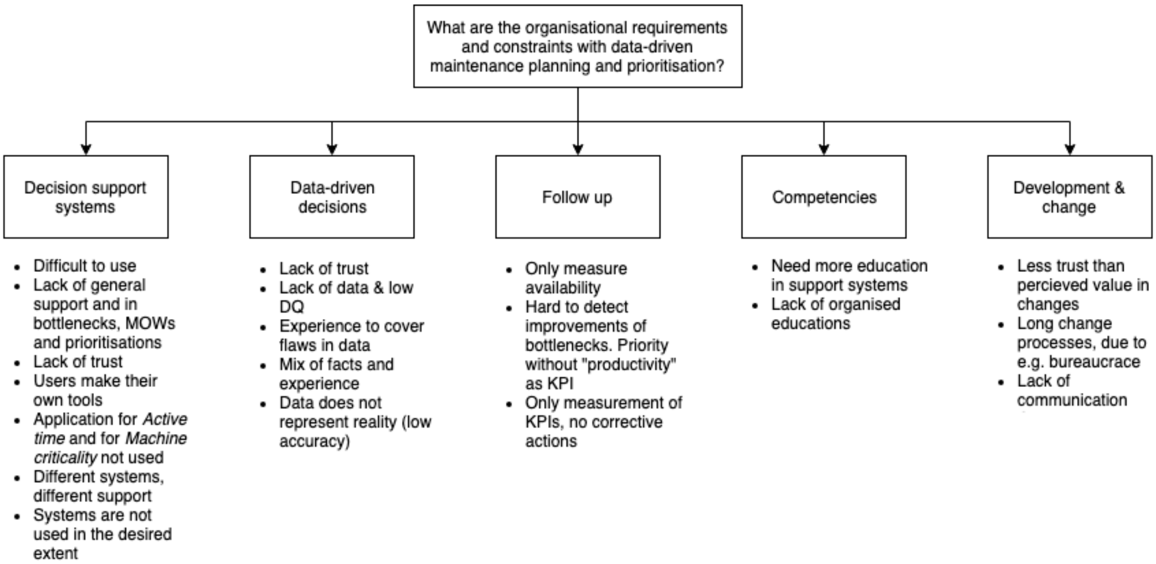

Figure 15. The five identified areas of constraints to data-driven maintenance planning and prioritisations.

From the research five areas of constraints were determined; *Decision support systems, Data-driven decisions, Competences*, *Development & change* and *Follow-up*. The areas are presented within each belonging constraints in Figure 15. Decision support systems are used in the organisation but they lack sufficient support in all areas, which makes users resort to developing their own tools. In the questionnaire there is no consensus if support is sufficient which is supported by the interviews where it is identified that systems provide much support but also lack in several areas. The criticism towards the systems are the lack of data or insufficient DQ and that systems are hard to maneuver. Moreover, as there are different systems in different shops, the given support and satisfaction differ among shops. Its mentioned that the support given by systems is insufficient but there are tools in the systems to meet some of the organisations needs, such as active time for bottleneck identification or machine criticality for PM prioritisations. However, both of these seem to lack of use with explanation due to insufficient DQ. In addition, another tool missing is support for exploiting MOWs.

data-driven decisions are used in the maintenance organisation at VCT, but it is noticed both in the questionnaire and the interviews that experience triumphs data and facts. What is noticed is that staff has to use experience as to cover for lack of data or DQ. Further, there is an opinion that data cannot fully be used for decisions but rather for measurement. Even though experience is used more than data and that there are flaws in DQ, the staff in general sees value in working more data-driven. However, technicians are more neutral towards the value which is explained by that their trust is lower as they see that data not always represent reality. That data is not accurate is something mentioned by other roles as well. It is also mentioned that the accuracy of data also affects the accuracy of the decisions taken by it, which is an explanation of the level of trust towards the data in the organisation. VCT is aware of the flaws in data and takes actions to improve it, but the flaws have to be fixed in order to increase the overall trust of data. The flaws further affect staffs trust in the support systems. Identified in the questionnaire is the lack of consensus of adequate preconditions to work with data, where in the interviews its mentioned that more education and time to work with data is needed. Regarding competences there seem to be some lacking resources for systematically organised educations for the maintenance organisation which makes people resort to competence development through learning by each other on the request by the individual. Which in turn makes it hard to identify if the organisation has the right competences for current systems, but also for new support systems.

The questionnaire and interviews both point out that there is a consensus regarding the importance of developing the maintenance work, while there is less trust towards the changes than the perceived value. An explanation to the trust can be due to the answers in the interviews that the perception is that top management focus more on quantity over quality in development projects and because of bureaucracy changes are long change processes that cause people to not notice changes happen. Moreover, there is a need to become better at communicating the benefits of changes. As to follow changes KPIs can be used, where it is mentioned in the questionnaire that there is a lack of consensus if KPIs are used for improving the maintenance work. In the interviews it was identified that KPIs are more used for measurement than for corrective actions. Additionally, some improvements by maintenance work might not be identified due to the maintenance organisations focus on availability rather than productivity.

7.3 Analysis of RQ2

The analysis is divided into one analysis for the subjective assessment, one analysis for the objective assessment and one combined analysis for the overall result of the research question.

7.3.1 Analysis of subjective assessment

It was determined from the providers perspective that the trustworthiness of the data is regarded to be high, but at the same time there is an uncertainty if it is enough. The users on the other hand do not share the same level of trust. The users suggest that it is important to understand what the data represents to fully be able to utilise the data, which could indicate that users have to complement the lack of accurate data with their own experience. However, the general opinion regarding DQ is that it is sufficient for current applications but needs further improvements, which could be contradicting as users still have to cover up for data with experience. To which extent the users has to cover for insufficient data is hard to judge**,** but there might be a larger issue with DQ than what the interviewees think, at least in the providers perspective.

There are different problems regarding the two types of in-data to Axxos. For issues in cycle-times there are in rare occasions missing or negative values in the in-data, which are easily detectable. However, less detectable problems might be missed in cases where there are existing values within the normal range but when value deviates from reality. For alarms, a critical issue is uncoded alarms where the manually entered data sometimes lacks in accuracy, as a result of wrong codes being entered or insufficient amount of information, which creates flaws in the DQ. Further, there are cases when coding of the alarms is not made in time, which causes delays in correct data being presented. These problems are affecting the overall accuracy of the data in Axxos and are contributing factors for discrepancies between data and reality. Even though these problems represent a large portion of the common problems it seems that manually coded alarms are necessary, as the PLCs are not capable of detecting and reporting all data. In addition, there are problems with false alarms which gives a distorted view of the reality. The outcome of the false alarms is that important alarms are not gathered as it gets blocked or missed due to attention to the false alarms. Further, there might be a hidden number of problems with the in-data that has not been noticed, both in alarms and cycle times. The deficiency of data or wrong data implicates a risk that decisions are established upon wrong rudiments, which further strengthen the users need to have experience of reality to correctly interpret the data. Lastly, the problems may affect the general trust of the data and decisions taken by it.

Axxos fulfills many of VCTs requirements within speed of data, easy access to data and analytic tools. The interface of Axxos provides a real-time view of the production system with minimum delay of the data. Further, the system provides easy access to relevant data and analytic tools. For the analytic tools there is a delay which makes the tools only presenting analyses of historical data, which results in real-time analytics cannot currently be performed. Moreover, the accessibility to data seems good as users can sort data within the interface or export for more advanced analytics. The data format seems manageable and understandable as all data is transformed through VD into the desired format, before arriving into Axxos. The only issue mentioned is that alarms are complex to transform which could implicate problems with DQ. As the transformation of data is done outside of Axxos it seems to give VCT better control of the transformation themselves and makes them less dependable on suppliers.

The organised quality assurance is performed through weekly meetings between staff from production and maintenance with the local Axxos specialist, where the goal is to intercept problems with Axxos. The approach is systematic for detecting quality issues, but it seems more reactive than proactive, as there is focus on remedying existing problems. Regarding proactive and systemic quality assurance it is identified that there might be a missing instance between IT and the local Axxos specialist. In the current situation there might be communication lacking between the two roles, which implicates a risk for lack of transparency, coordination and holistic overview for the quality assurance. On the other side the capability for being reactive within the organisation to solve detected problem is regarded to be enough. Where the organisation has the competences for solving the majority of issues inhouse and the escalation paths seem to be well known for occasions where problems cannot be solved within VCT. Determined from the interviews is that the most important work with quality assurance is detecting and reporting of problems by the organisation, as IT and local Axxos specialist cannot detect all problems. Which indicates that the organisation has to be involved to a larger extent in the quality assurance. This, since the staff in maintenance and production have insights in the context and could more easily determine if data represents reality, while both IT and the specialist might lack understanding in context dependable problems and cannot monitor all daily changes. Mentioned as a way to engage more staff to identify and report more issues with the data there is need for further educating staff in Axxos to increase the overall interest in the system.

The bottleneck identification tool *Active time* seems not to be used at VCT, as the interviewees had little recollection of it. It was mentioned that VCT had been asked to evaluate the tool, but it does not yet seem to have been performed. What could be determined is that the staff has not got any good introduction of the tool and how to utilise it. Both IT and the specialist did however suggest that if the tool is to be used more in the future, it could be necessary to do an overhaul of the DQ as to ensure the sufficiency of decisions taken of it. Lastly, it is considered important to validate the accuracy of the tool before fully utilising it in the organisation.

7.3.2 Analysis of objective assessment

Overall the objective assessment showed the DQ to be sufficient, except from some deviating cycle time values with unacceptable values. The values between the datasets correspond well, where only one deviation was identified. The deviation could be explained if Axxos process data differently than VD. There were more samples of cycle times tested as it could be automated, while there were less samples in the alarms as they had to be manually tested. Five indicators were used for objectively assessing the DQ, where the indicators used were; accessibility, consistency, credibility, integrity and readability. The data was easily accessed in the datasets and was provided in a clear and understandable format which meets the specification and thereby indicated that there is an integrity in the data. Since the data is provided in acceptable values and corresponds well between the datasets, the consistency credibility is considered to be sufficient. Lastly, the data was only tested through a context-independent perspective and no assessment of whether the data represent the reality was performed.

7.3.3 Combined analysis

Identified in both the subjective and objective assessment was that the overall DQ seems to be good. There are not many distinct problems in the data, but there could be hidden numbers in errors that are not easily detectable. This can be strengthened by the objective assessment where the quality issues that were detected were the obvious ones. Not found in the objective assessment are context dependable problems that only experienced staff could notice, such as small deviations between data and reality. This raises the question of how much deviation the system has to reality. It was mentioned that an occurring problem were false alarms or incorrect coded alarms, these alarms were also hard to separate from the high quantity of alarms during the objective assessment. Separating false alarms from real ones is a further thing seem to need experience of the context. What could be said about the alarms is that the standard was easy to follow and that there were no deviations between VD and Axxos. The combined results of the assessments indicate that the DQ seems to be sufficient for current applications, but that there are still quality issues prevalent in the organisation. Further, the identified quality issues in the objective assessment are not determined to be of such a magnitude that it could indicate that there is an overall issue with DQ at VCT. However, important to notice is that the objective assessment could not detect context dependable issues and that it correlates to that the providers also might have a hard time to notice them. There could be hidden issues in the DQ and it is therefore necessary to engage the staff more to identify them. Seen in Figure 16 the main identified matters are presented in three areas *Current state, Constraints* and *Future*. In *Current state* common data quality problems are presented, in *Constraints* the overall constraining factors in the data quality are presented and in *Future* issues that need to be handled in the future are presented.

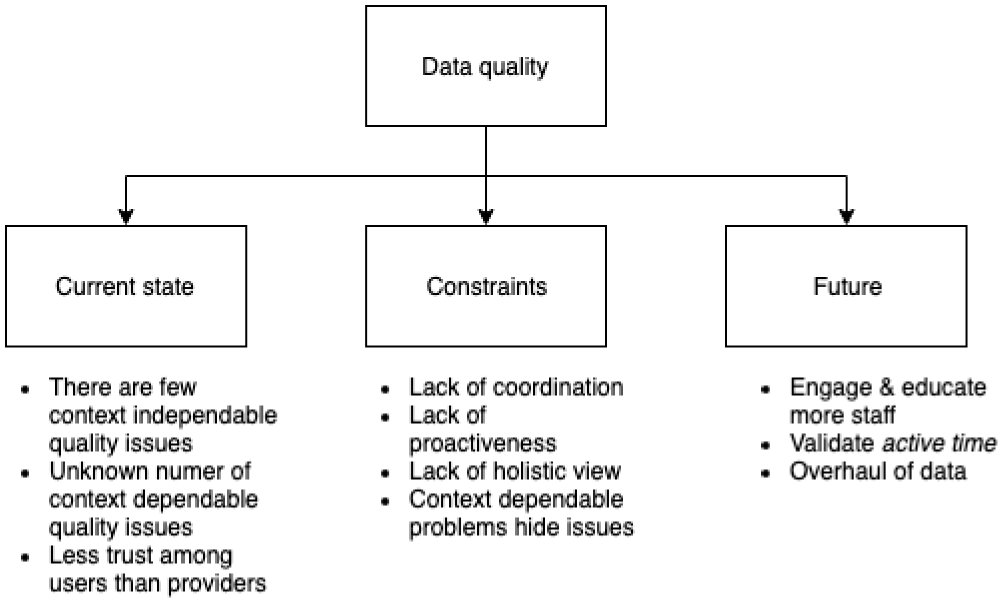

Figure 16. Key takeaways from the analysis of the combined data quality assessment.

8 OVERALL DISCUSSION

This chapter presents discussions regarding the key outputs, methodology, and implications to both industry and academia.

8.1 Result discussion

The results obtained in the thesis show that prioritisations are very important for VCT where there is a clear value in prioritisations, even though there is uncertainty in which types of maintenance that needs prioritisations. It is remarkable that prioritisations are performed ad-hoc based-on experience when it is of such operational importance for VCT, especially when there are existing tools which could provide necessary data-driven decision support. Not to be neglected is that the staff is highly competent but relying solely on selected individuals creates a vulnerability of being dependable to the individuals. Additionally, the use of data could increase the objectiveness in the decisions, by reducing the amount of guesswork and lack of holistic view (Gopalakrishnan, 2018). Identified is that the maintenance organisation has the willpower to become more data-driven, but currently there are constraining factors impeding the transformation. Presented in Figure 17 are the determined constraints for VCT where the main areas are *Support systems, Data quality, Organisational factors, Change management,* and *performance measure*. In addition, to fully cope with the amount of maintenance two further improve areas were identified as more exploitation of MOWs and optimising PM intervals, each with own inherent constraints as presented in Figure 17.

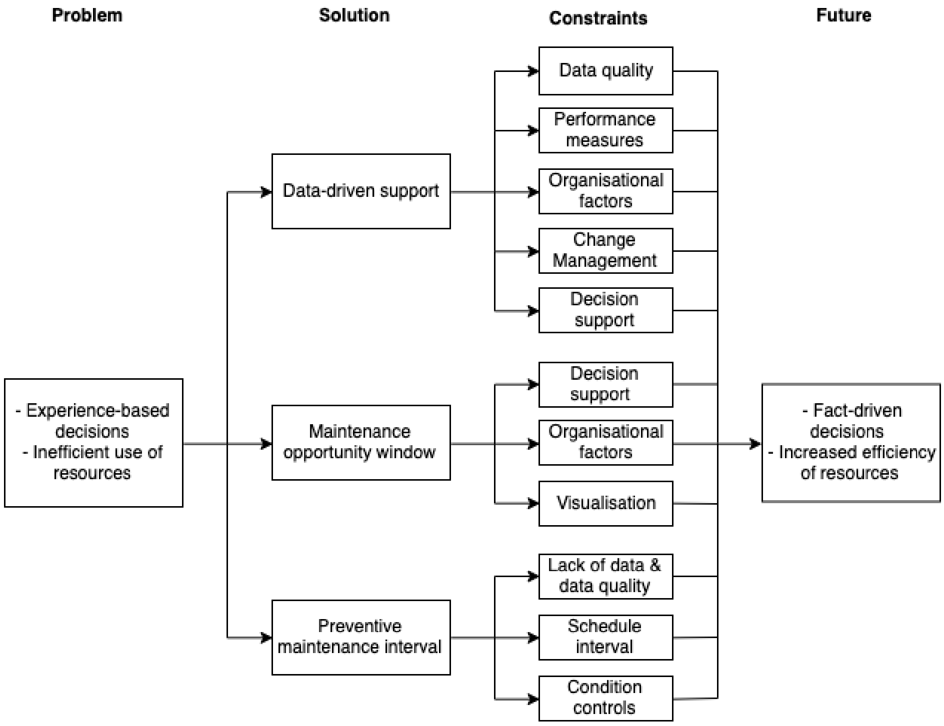

Figure 17. Constraints at VCT to data-driven decisions.

The support systems have been shown to provide deficient support, which obstructs the maintenance organisation at VCT to becoming more data-driven. To increase the use and trust in the systems, the support systems need to become easier to use and provide the desired applications. On the other hand, in some areas the systems provide more support than what is used, where there is currently system support for data-driven planning and prioritising of maintenance with both tools in machine criticality for work orders and bottleneck identification. Moreover, it is remarkable that VCT has been engaged in the research project that resulted in that Axxos implemented *Active time* in its system (Gopalakrishnan, Subramaniyan, Salonen, Asp & Archenti, 2019b), while not utilising the tool. It seems that the tool has been insufficiently communicated towards the organisations; if VCT would like to use it more, it is recommended to invest more time in communication and training in the tool. According to Subramaniyan et al. (2016) there are significant improvements with regards to overall throughput of the system with using the tool, even though the performance of the tool has not been validated at VCT it can be determined that they might miss a great opportunity. Further, there is improvement potential in the machine criticality function in Maximo, that could be used to fully give the support that planners need to become data-driven. To overcome the issues with the criticality function there is need for stricter guidelines around how to set the criticality or to base the criticality in order approaches such as using the bottleneck identification tool for basing the priority in the production system. The main issues with the decision support systems at VCT are likely to be rooted in flaws in the DQ, which affects the trust in data, data-driven decisions and the support systems. Identified in RQ1 and RQ2 are two different views of the level of DQ in the body shop at VCT. What the reason is why users and providers of the data have different opinions regarding the DQ, could be explained by that the users have higher possibility of detecting context dependable problems. Even though in RQ2 it is determined that DQ is sufficient, it is deemed in RQ1 that there are large problems with DQ that is affecting the trust in the organisation. The extent of the problems is hard to identify, but it is enough to make the workforce cautious towards data. The lack of trust in data is a constraint to consider, in order to turn the attitude of the organisation there is a need for an overhaul of the DQ as to pursue the transformation into becoming more data-driven. In addition to improve the DQ it is recommended to perform a validation of *Active time* before using it more.

There are factors concerning the workforce that is further constraining the organisation from becoming more data-driven. There is a problem with DQ in Maximo which is due to staff not having time to fully report work and also due to complex systems which makes it hard to fill in the right information. These problems affect the completeness of the data in Maximo. To overcome the problems staff, need for more scheduled time to reporting work into the systems and for more training in becoming more proficient in the systems. There is a vulnerability in competence development as the maintenance organisation relies mainly on skills transfers between single individuals, which makes the organisation unaware of which knowledge is transferred and thereby decreases the control of competences. Skills transfers are an efficient way of competence development, but there is an improvement potential in systemsing competence development in a larger extent. By a systematic education the organisation could have a larger control of competences, make sure that all employees have the same base to work from and make it easier to push new work methods.

Regarding an additional area there is a positive attitude towards development and change in the maintenance organisation, but the workforce is more hesitant to the implementations. The critical view on changes could affect the commitment of staff, which in turn could have negative effects on the successfulness of developments. To meet their criticisms, it was identified that staff wants more clarity in communication regarding benefits of changes, which makes staff comprehending in why to commit to the changes. Further, there is a need of the management to focus more on the outcome of developments, but also to follow up effects of the implementations. Moreover, the organisation might not be able to identify all improvements regarding prioritisations of maintenance as they only track technical availability and not productivity. To fully identify the improvements gained from prioritisations to bottlenecks, thus improvement to system performance, the organisation has to follow and measure productivity as well (Parida & Kumar, 2009; Ylipää at al., 2016). On other hand, technical availability mainly provides information of the uptime of individual machines and consequently not taking the system perspective into consideration (Gopalakrishnan, 2018). In addition, there is a constraint that the organisation is lacking in taking corrective actions from KPIs and is rather passive for mainly using KPIs for measurements, which could constraint in improving of the operations.

Additional areas that need improvements for managing all the PM at VCT is to increase the number of exploited MOWs and improve the intervals for PM. Regarding MOWs there are according to Li & Ni (2009) large benefits of exploiting MOWs which could increase the amount of PM performed. Currently there is a lack of support in exploitation of MOWs, both in the organisation and in the decision support systems. The lack of support could be improved by visualising MOWs and also highlighting of which work orders that could be performed during the window. Moreover, the organisation could change approach to allow the exploitation of MOWs to access the long-term benefits with them, rather than trying to fill buffers to the limit to get short-term gains. In addition, there is a need for optimising the PM intervals which could be done through more condition controls to adjust the interval and by scheduling intervals dynamically on performed cycles rather than statically on number of weeks. Currently there is also a constraint that intervals are based mainly on experience in combination with supplier data, where the data could be biased for insurance reasons. Instead, the organisation could benefit from rather basing intervals on reliable data which could help the intervals to be optimised.

If VCT would consider the identified constraints and to take corrective measures by them they could take benefit of increased efficiency and productivity of the production system. The factors that could give VCT the benefits are through fact-based decisions and focus more on a holistic view of the production system, which in turn could lead to right prioritisations of maintenance but also more PM being performed. Additionally, there are benefits in sustainability as there is a possibility to utilise limited resources in a more efficient way, where the capacity of a production system can be increased without using more resources (Gopalakrishnan et al., 2019a). Increasing capacity without adding more resources has positive effects in economic as well as environmental sustainability, which is in line with the doing more with less mindset which is determined by the European Union (EU) to be a future challenge for the industry and EU at large (European Commision, 2008).

8.2 Methodological discussion

The overall methodology for RQ1 provided perspectives from several parts of the maintenance organisation and areas. Basing the research on quantitative data enabled exploration in broad areas combined with interviews which provided deeper explanations. The questionnaire provided good support for building the research on but had the weakness of uneven distribution between different segment groups. The results would have been stronger if there were more answers from both TC and maintenance technicians, as these were the groups with lowest response rate. However, in general the response rates were reasonably adequate for basing the analysis on. Moreover, in hindsight some questions could have been reformulated to create more clarity. Examples of reformulation are the questions regarding *Active time,* were it was later in the study identified that the tool is found in the tab *bottleneck analytics* in Axxos which could be a reason why few knew about the tool as it is not directly labeled *Active time*. Even though the lack of clarity in the questionnaire the lack of knowledge and use of the tool could be verified through other insights from both the pre-study and interviews in RQ2. The interviews in RQ1 provided good insights into the maintenance organisation in general and in TA. Moreover, as the scope was set on TA there were unfortunately perspectives lost that could have brought a deeper understanding for both TB and TC. However, in overall the investigation provided the explanations necessary for answering RQ1.

The methodology for RQ2 in general provided a good investigation with comparisons in different perspectives and approaches for assessment. There were two things where the study lacked depth which were in user's perspective and context dependable DQ issues. To avoid the lack of depth in user's perspective more users could have been interviewed to diversify the opinions about DQ. In regard to the objective assessment it could mainly find context independent DQ issues as a lack of experience of the production system. What could have been done differently to identify context dependable DQ issues could have been through consulting experienced staff regarding the accuracy of the studied data. Moreover, the objective assessment only provided small samples of the overall data and to fully objectively assess the data the study would have had to been done in a larger extent. The results however show an indication of what issues that exist at in the body shop at VCT. In addition, the flaws of the study in RQ2 were covered by insights gained in RQ1, in combination the two studies provide an elaborated result regarding the DQ.

8.3 Implications for industry and academia

Research in general within data-driven planning and prioritisation of maintenance has earlier been focused on technological advancements and developments of maintenance practices. In contrary to earlier research, this thesis focuses more on organisational aspects and provides examples of organisational challenges that is constraining the implementation of the advancements. The findings could be good complement to the technological focused research as to highlight other important factors before taking the step into becoming more data-driven in planning and prioritisation of maintenance. Even though the results of this thesis are mainly obtained from the body shop at VCT, the results could probably also be applied to the other shops as well as other industries. Thus, the result and discussion of this this could be used as a guidance in what constraints exist, what their implications could be and how other industries could avoid them. As Bokrantz et al. (2017) mentions there is a gap between research and industry, what was discovered in this thesis is that even though industry participates in research projects they sometimes lack knowledge of how to implement the research. If academia is interested in pushing innovations in the maintenance field forward there could be a need for more clarity in communications regarding benefits of the research and in how to implement the research.

9 CONCLUSIONS

The aim of the thesis was to investigate the VCTs maintenance organisations readiness to adapt more data-driven approaches for planning and prioritising maintenance. There are clearly values in prioritising maintenance through data-driven approaches which are applicable for VCT. The maintenance organisation at VCT has earlier been engaged in research projects to develop their maintenance practices but it has not shown enough results. The results of this thesis identify the constraints that are a hindrance for the maintenance organisation at VCT to become more data-driven. There are already many prerequisites existing for taking the step forward, such as support systems, tools and the attitude towards becoming more data-driven.

According to RQ1 and the constraints for becoming more data-driven are within *Data quality, Support systems, Change management, Organisational factors* and *Performance measures.* There have to be improvements in DQ and enhancements in the support given in the support systems. More systematic education has to be given to increase the ability to utilise the support provided. In addition, benefits of changes have to be communicated more efficiently to engage the workforce in a coming implementation of data-driven maintenance work methods. Lastly, to fully detect the improvements of data-driven planning and prioritisations new performance indicators in productivity has to be followed in the maintenance organisation instead of working towards technical availability. Moreover, the organisation has to further optimise PM intervals to reduce unnecessary work and to develop support in exploiting MOWs to increase opportunities to perform maintenance activities. In RQ2 it could be concluded that there are few context independent DQ issues but that there might be hidden numbers in context dependable issues. If using *Active time* on a larger scale the function of the tool has to be validated and there has to be an overhaul of the DQ in Axxos. Concluded from both RQ1 and RQ2 is that the DQ is lacking and need further improvement.

Coupled to the aim, the thesis has shown VCTs readiness to adapt data-driven approaches for planning and prioritisation in maintenance. What has been identified are the constraints that exist in both the organisation and in DQ that is a hindrance for VCTs transformation in becoming more data-driven in maintenance. The organisation has many prerequisites for working more data-driven and the system support is already existing. There is a drive within the organisation for becoming more data-driven, where the workforce sees many benefits. But the areas of improvements are currently constraining VCT to take the next step into becoming more data-driven within maintenance. The constraints that VCT faces could also be considered in other companies and industries. Consequently, DQ and insufficient decision support are two constraints among others that could be prevalent elsewhere. If VCT would overcome the identified the constraints, they could become more-data-driven and could take part of many benefits. Lastly, what can be concluded based on the findings in this research is that the maintenance organisation at VCT are facing several constraints that will have to be overcome in order to become a data-driven maintenance organisation. This thesis has considered a large automotive manufacturer; however it is suggested that the findings can be applied for many other companies and industries to guide them in their journeys in becoming more data-driven.

9.1 Future research

In regard to the technological aspects there is a need for validation through a case study of the benefits and needs for prioritising maintenance towards bottlenecks using active time as an identification method, in this thesis the need was mostly confined to PM. In earlier research focus has been on RM but from this research project an uncertainty in the true need has been identified. Regarding the prioritisation methods further developments are needed in methods that take the type of work order into consideration when prioritising, as prioritising solely to bottleneck equipment might create situations where more critical work orders are down prioritised and cause a stop in the production.

The future for the organisational factors there is a need to further make a roadmap organisational constraints, what their implications are and how to overcome them. Further, there is a need for industry-wide study to identify additional constraints, to validate the results of this research and to find similarities or discrepancies between other companies. There are possibilities for further research in whether these results are true only for the field of maintenance or if they are applicable for organisations in for an example quality or production as well.

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APPENDIX A - DATA QUALITY INDICATORS

Table is based on the data quality dimension, elements and indicators suggested by Pipino et al (2002) and Cai & Zhu (2015).

Dimensions	Elements	Indicators
Availability	Accessibility	Whether a data access-interface is provided
	Timeliness	Within a given time, whether the data arrive on time
		Whether data are regularly updated
		Whether the time interval from data collection and processing to release, meets requirements
Usability	Credibility	Experts or specialists regularly audit and check the correctness of the data content
		Data exist in the range of known or acceptable values
Reliability	Accuracy	Data provided are accurate
		Data representation (or value) well reflects the true state of the source information
	Consistency	During a certain time, data remain consistent and verifiable
	Integrity	Data format is clear and meets the criteria
	Completeness	Whether the deficiency of a component will impact data accuracy and integrity
Relevance	Fitness	Most datasets retrieved are within the retrieval theme users need
Presentation quality	Readability	Data (content, format, etc.) are clear and understandable
		It is easy to judge that the data provided meet needs

APPENDIX B - UNSTRUCTURED INTERVIEWS

In this appendix the answers from the unstructured interviews are presented. The answers are divided into a section with general information of the maintenance organisation and one more specific of preventive maintenance planning.

General

VCC has different plants around the world with different purposes, the plants with the same purpose are quite similar and follow a general structure. There are many global forums for knowledge sharing and VCC adapt different standards for the overall organisation to follow. Result of this is that the plants share similar processes, practices and system worldwide. Further, many innovations at one plant might thus be transferable to other locations. The car manufacturing factories are in general divided into different shops after the manufacturing processes car body assembling, painting and final assembly. At VCT the processes are accordingly into three shops, body shop (TA), paint shop (TB) and assembly shop (TC).

Maintenance organisation

The maintenance organisation at the VCT factory is divided into two levels, plant maintenance and local maintenance organisation. The plant maintenance department is responsible for development in work methods, practices and technology, in maintenance at the plant. For each shop there is one local maintenance organisation, which is responsible for the local maintenance activities such as reactive maintenance, preventive maintenance and improvement projects. Working in the shops are technicians, engineers, planners, leaders and manager. Further, there is a control bridge in each shop which has a visual of machine status and breakdowns of the whole factory and every line. The control bridge receives work order requests and creates work orders that are communitacted and assigned to maintenance technicians and engineers. In order to align the work between shops the plant maintenance department is responsible for cooperation between shops, which is done through weekly meetings to share knowledge, latest updates and goals. Despite the shops being dependent on each other, they also face different challenges and have different approaches for the maintenance work.

The shops all work with computerised management systems, but different systems are used in different shops. Overall in VCT one CMMS is used which is called Maximo, which is a tool for managing maintenance work orders and inventory control for spare parts. Further, in each shop there is a local MES to monitor disturbances in the production system, which constantly keeps track of the production system. TA has the most modern and recent MES which is Axxos, the system will be the new standard for MES at VCC and VCT will in the future change to Axxos in the other two shops. In the Axxos there is a function named *active time* that provides real-time identification of bottleneck machines. The function is not used at VCT but could provide the data support necessary for prioritising maintenance. The use of different systems complicates the possibility to share and use production data among the shops. The local maintenance departments are aiming towards making fact-based decisions, but not sufficient effort is spent on working with data analytics to plan and prioritise maintenance. A contributing factor mentioned is the poor use of data is due to the use of outdated systems that are not optimised for its purpose.

The shops all work actively with KPIs to continuously follow up the performance. The three major KPIs are *mean downtime* (MDT), *technical availability,* and *mean cycles before failure* (MCBF).

Preventive maintenance planning

At VCT preventive maintenance (PM) is planned at a local level, while there is support at central level. The central planner is responsible for developing the planning processes and helping the local planners with tools for planning PM. The local planners perform the actual planning and prioritisation of the PM work orders. In TA and TC there is one planner for each factory. In TB there are three planners, each responsible for one area of the shop, by themselves.

The process for PM consists of the stages requests, preparation, planning and performing. In order for a PM activity to be performed a request has to be sent. The requests may come from any function in the organisation, but mainly come from technicians after inspections if they have noticed deviations that need to be corrected. When engineers request PM, it is often when there is need for a new PM plan for a specific machine. All requests are handled within Maximo where the requester enters all necessary data of the machines. After a request is made, a prepper has to go through the request and decide whether it should be performed and if there is enough information in the request or performing PM. The prepper order material among other things so that the work orders can be performed. After preparation the planner take over; they prioritise and plan the maintenance activities. A work order is given team or person performing the activity and assigns the time it should be performed. It is up to the planner allocate the necessary resources. The planners are responsible for prioritising between PM activities and they often prioritise by their experience.

The planning is done as late as possible and the majority of the work orders that requires more than 30 minutes of work are scheduled for the weekends, since the production is already stopped. It is common practice to plan more PM activities than they could manage in the given time frame, as they never want the technicians to be out of work orders to perform. This is especially important during weekends when the production is stopped. However, they try to finish 90% of all planned jobs in time. Regarding stop times they have a problem with PM work orders as they often might not be detailed enough, which results in that mostly all PM is performed during stop time even though some work orders might be alright to perform during production. Sometimes they also might have a shortage of work orders they can perform during running production. Some challenges have been noticed about PM which has to do with PM plans for individual machines and machine criticality. PM plans they are scheduled after machine supplier’s recommendation rather than what is regarded best for VCT. Further there is set machine criticality for all the shops within Maximo, but it is said to be most likely not used and that the existing machine criticality might not be up to date.

APPENDIX C - OBSERVATIONS

This appendix will cover a summary of the observations that took place for answering RQ1.

The bridge is a location which has an overview of all alarms within the factory and there is one bridge in each factory (body shop, painting shop and assembly shop). The operator at the bridge processes work orders for reactive maintenance. These work orders can come from alarms from the control systems for the factory or they come from personnel in the factory that call in breakdowns. In TC the alarms come from an automated system that the bridge operator has to process and then send personnel to. Within TA the bridge operator has to monitor the control system actively to identify the alarms. After the work order is gathered the bridge operator calls for maintenance technicians that have right competences for performing the work order.

In TA reactive maintenance work orders are mostly not prioritised and they are processed as they come in a first-in-first-out (FIFO) approach. In some cases, work orders are prioritised when there are many work orders, then they prioritise production-critical failures over non-production critical failures. The prioritisation is performed by a combination of experience with analysing the control system for determining if the breakdown is stopping production or not. Usually the amount of work orders is not many and there is not a strong need for prioritising between work orders. However, the breakdowns that occur is often time consuming and take long time to fix.