



School of Innovation, Design and Engineering

Importance of system integration on the results of measuring performance – A case study in a manufacturing company

Master thesis work
30 credits, Advanced level

Product and process development
Production and Logistics

Afnan Al-Mbaideen
Gizem Plamenova Davidova

Commissioned by: Scania Industrial Maintenance
Tutor (company): Anders Tiger
Tutor (university): Marcus Bengtsson
Examiner: Antti Salonen

ABSTRACT

Background:	The maintenance process is crucial for production activities to supply continuity and productivity. With Industry 4.0 advent, opportunities to create a huge amount of data and use this data to improve production and maintenance performance indicators became a topic that is necessary to make decisions. Most importantly, before applying these technologies, there is a need to integrate all systems to create a common language.
Purpose:	The first aim is to explore the influence of system integration within production and maintenance in measuring machine availability. Secondly, to review in detail the procedure of calculating machine availability among several production units in a manufacturing company.
Research Question 1 (RQ1):	What are the values of system integration among maintenance and production decisions in measuring machine availability?
Research Question 2 (RQ2):	Which parameters or indicators can be taken into consideration to calculate machine availability among several production units in a manufacturing company?
Methodology	The study is based on a case study that primarily relies on qualitative data from interviews, survey, and observations, as well as quantitative calculation of availability data. An exploratory research design was used in the beginning of the study, followed by an abductive approach which means both inductive and deductive approach were used. The total process can be broken down into two parts: theoretical background/literature review and Scania empirical research.
Conclusions	With the integration of different systems, it is shown that the real availability numbers differ compared with assumed numbers. The manufacturing industry is undergoing paradigm shifts, and many manufacturing companies worldwide are currently updating their maintenance strategies aligned with smart maintenance. With the aim of securing productive, robust, and sustainable production systems through the implementation of the smart maintenance concept. Therefore, it can be suggested that before implementing smart maintenance technologies, starting to create collaboration within a common database in association with production units about production data sharing matter is crucial step for the case company.
Keywords	System Integration, Maintenance, Information Sharing, Availability.

ACKNOWLEDGEMENTS

First and foremost, we would like to express our sincere gratitude to everyone that has contributed to our work, especially to our beloved supervisor at Mälardalen University, Associate Professor Marcus Bengtsson, for the continuous support during the study, his motivation, enthusiasm, and immense knowledge. We could not have imagined having a better advisor and mentor for the study. Besides our supervisor, we are extremely grateful to our mentor at Scania Industrial Maintenance, Anders Tiger, who provided us the opportunity to be part of this inspiring work and for his support during the thesis work. Furthermore, thanks should also go to all people from both Scania AB and Scania Industrial Maintenance for their co-operation during the study.

We are also grateful to all our teachers during the last two years in our master's program for their endless information, experience, guidance, motivation, and support. They helped and supported us personally and professionally. Many thanks for our professor, Antti Salonen and PhD student San Giliyana for their endless support and cooperation, they were beloved friends before being our teachers. They inspired us to achieve high standards of learning and education levels.

Finally, we could not have undertaken this journey without our precious family, partners, and friends and we are thankful for their continuous support and comforting words.

Afnan Al-Mbaideen
Gizem Plamenova Davidova

Lastly, this publication has been produced during my scholarship period at Mälardalen University, funded by the Swedish Institute.

Afnan Al-Mbaideen

Table of Contents

1. INTRODUCTION	1
1.1. BACKGROUND	1
1.2. PROBLEM FORMULATION	2
1.3. AIM AND RESEARCH QUESTIONS	3
1.4. PROJECT LIMITATIONS	3
1.5. THESIS OUTLINE	4
2. RESEARCH METHOD	5
2.1. RESEARCH PROCESS AND DESIGN	5
2.1.1. <i>Literature Review</i>	6
2.1.2. <i>Case study</i>	7
2.2. DATA COLLECTION	7
2.2.1. <i>Literature Review</i>	7
2.2.2. <i>Case study</i>	9
2.3. DATA ANALYSIS	10
2.3.1. <i>Literature Review</i>	10
2.3.2. <i>Case Study</i>	11
2.4. QUALITY OF THE RESEARCH	12
3. THEORETIC FRAMEWORK	13
3.1. PRODUCTION SYSTEMS IN MANUFACTURING INDUSTRY	13
3.1.1. <i>Information sharing</i>	13
3.1.2. <i>System Integration</i>	14
3.2. INDUSTRIAL MAINTENANCE	15
3.2.1. <i>Computerized maintenance management system (CMMS)</i>	15
3.3. PERFORMANCE MEASUREMENT IN MANUFACTURING INDUSTRY	16
3.4. MAINTENANCE PERFORMANCE INDICATORS	17
3.4.1. <i>Maintenance process (leading) indicator</i>	18
3.4.2. <i>Maintenance results (lagging) indicators</i>	19
3.4.3. <i>Availability</i>	19
3.5. SMART MAINTENANCE	20
4. RESULT (EMPIRICS)	23
4.1. CASE COMPANY – SCANIA	23
4.1.1. <i>Scania in Sweden</i>	24
4.1.2. <i>Scania Industrial Maintenance (SIM)</i>	24
4.1.3. <i>Scania Information Systems</i>	25
4.2. WAY OF WORKING IN DIFFERENT PRODUCTION UNITS AT SCANIA	28
4.2.1. <i>Way of working of DT</i>	28
4.2.2. <i>Way of working of DX</i>	30
4.3. SURVEY	32
5. ANALYSIS	35
5.1. GENERAL ANALYSIS	35
5.2. ANALYSIS OF RQ1	36
5.3. ANALYSIS OF RQ2	38
5.4. AVAILABILITY CALCULATIONS	40
5.4.1. <i>Availability Calculations for DT</i>	40
5.4.2. <i>Availability Calculations for DX</i>	40
5.4.3. <i>General summary of calculations in DX and DT</i>	41
6. CONCLUSIONS AND RECOMMENDATIONS	43
7. REFERENCES	45
<i>APPENDICES</i>	52

ABBREVIATIONS

3D	Three Dimensional
AI	Artificial Intelligence
BI	Business Intelligence
CI	Continuous Improvement
CMMS	Computerized Maintenance Management Systems
CPS	Cyber Physical Systems
ERP	Enterprise Resource Planning
HSSE	Health, Safety, Security and Environment
ICT	Information and Communication Technologies
ICM	Immediate Corrective Maintenance
IDT	School of Innovation, Design and Engineering
IOE	Internet of Everything
IoT	Internet of Things
IT	Information Technology
KPI	Key Performance Indicator
MDU	Mälardalen University
MES	Manufacturing Execution System
MM	Maintenance Management
MOM	Manufacturing Operations Management
MPM	Maintenance Performance Measurement
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
OEE	Overall Equipment Efficiency
OPE	Overall Process Effectiveness

P&L	Production and Logistics
PI	Performance Indicator
PISA	Production Information Systems Architecture
PLC	Programmable Logic Controller
PM	Preventive Maintenance
PMS	Performance Measurement Systems
PRU	Production Unit
RAMS	Reliability, Availability, Maintainability Study
SCADA	Supervisory Control and Data Acquisition
SIM	Scania Industrial Maintenance
SMDSS	Smart Maintenance Decision Support Systems
SPS	Scania Production System
UI	User interface

List of figures

Figure 1: Research Process adapted from Fagerström (2004).	5
Figure 2: Chronological workflow of the key points in the research.....	6
Figure 3: Triangulation methodology	6
Figure 4: The road map within questions which were asked during writing (adopted from Säfsten & Gustavsson, 2020)	12
Figure 5: ISA-95 Levels	25
Figure 6: Connection between information systems at Scania	28

List of tables

Table 1: Data collection methods	7
Table 2: Keywords to search in databases	8
Table 3: List of interviewed employees	9
Table 4: Categorization of Articles	11
Table 5: Swedish standard definitions of RAMS	19
Table 6: Availability calculations from literature	20
Table 7: The main 9 pillars of Industry 4.0 and explanation (Erboz, 2017)	20
Table 8: Total planned production time according to shift tables at DT.....	30
Table 9: Weekly production planning in hours for DX	31
Table 10: Respondents of survey	32
Table 11: Questions and answers related to current calculations of machine availability	32
Table 12: Responsible person, system, and formula of calculation.	33
Table 13: Details of calculating machine availability	33
Table 14: Problems of calculating machine availability	34
Table 15: Future suggestions for calculating machine availability	34
Table 16: Availability calculations for DT	40
Table 17: Availability calculations for DX	41
Table 18: Total number of work orders calculations for DX.....	41
Table 19: Total selected work orders and calculation difference for this study	42

List of pictures

Picture 1: Production planning for Central Gear product for 2022.....	29
Picture 2: Production planning for Special Axle product for 2022.....	29
Picture 3: Example from 3 shifts planned production.....	31
Picture 4: Example from 4 shifts planned production.....	31
Picture 5: The current data tables in Data Lake from Ebba	35

1. INTRODUCTION

This section sheds light on the background of the integration between production and maintenance environments and its importance in measuring the performance parameters. Following, the problem formulation, aim and research questions are presented, in addition to the project limitations.

1.1. Background

The maintenance process is a significant contributory factor to the development of high productivity of production facilities (Misztal, et al., 2014; Mostafa, et al., 2015; Franciosi, et al., 2020; Lundgren, et al., 2020). Effective maintenance management requires an understanding of the integration between both the production and maintenance environments (Frost, et al., 2019). In fact, production and maintenance planning are dependent on each other to a significant extent (Schreiber, et al., 2019). To illustrate, the function of the production department is to achieve the production targets according to the optimum capacity to produce and fulfil customers' requirements while the goal of the maintenance department is to optimize the performance of the production system and machine availability through maintenance activities (Liu, et al., 2015). Historically, the interconnection between production and maintenance has been described by contradiction (Rishel & Christy, 1996). In the same vein, other research (Liu, et al., 2017; Rahmati, et al., 2018) hold the view that production planning and maintenance planning are addressed as individual problems. For this reason, Arab, et al. (2013) argue the complexity in the production environment has a considerable impact on increasing the complexity of maintenance actions.

Therefore, as stated by Algabroun, et al. (2017) integration is an approach that intends to 'tie together' several elements and components to organize a system. Likewise, Xiang, et al. (2018) mention that information integration is a principle that systemizes and controls information for a defined objective or for a particular work. Al-Najjar (2002) highlights the benefit of having a common database that supports the smooth integration of the databases of the factories' operations aiming for raising the company's profits due to the fact of identifying and eliminating both quality problems and failure reasons at the very beginning. Besides, previous research into improving the integration between organizational functions has focused on maintenance and production (Algabroun, et al., 2017; Ruschel, et al., 2017,). Gopalakrishnan, et al. (2022) point out that industrial maintenance, production planning, and control are pillars and well-structured foundations for boosting productivity in manufacturing companies.

The relevance of the maintenance function should be recognized since it can have an impact on production operations and business processes by guaranteeing system safety and lowering operational expenses over the system's lifetime (Aboelmaged, 2015). For this reason, companies utilize computerized maintenance management systems (CMMS), and new-generation systems, such as eMaintenance, Industry 4.0, and Maintenance 4.0, are gaining traction, where data is collected from many sources and integrated through the systems (Metso, 2018). According to Tretten and Karim (2014), integrating the CMMS with other systems improves the efficiency and effectiveness of the maintenance management (MM) process. Nonetheless, as stated by Wong, et al. (2013) common database has a pivotal role in connecting maintenance and production together in a perfect manner and therefore sustaining high productiveness. In recent years, there has been an increasing amount of literature from researchers and practitioners about maintenance performance measurement (MPM) due to the change of direction in maintenance

(Parida & Kumar, 2006). MPM is defined as an integrative process of measuring and identifying the added value by maintenance investment and paying attention to the organizations' stockholders' necessities being viewed strategically from the overall business perspective (Parida & Chattopadhyay, 2007). In fact, the scope of maintenance has shifted from "necessary evil" to an "integral part of the business process". Therefore, the measurement of maintenance performance is crucial for a wide range of scientific and industrial processes (Parida & Kumar, 2006). According to Lindberg, et al. (2015), the measurement of maintenance performance is a challenging task when the industry has several types of machines to manage and control. Therefore, the manufacturing industry has combined numerous measurement systems to evaluate the performance of manufacturing operation actions, named performance measurement systems (PMS) (Kang, et al., 2016). PMS is explained as a set of metrics with the purpose to measure both efficiency and effectiveness of manufacturing operations (Neely, et al., 2005). Bengtsson and Salonen (2015) discuss the need of focusing on both efficiency and effectiveness to achieve total effective maintenance. Performance measurement plays a critical role in managing maintenance actions. Clearly defined performance indicators (PIs) are a fundamental property in identifying performance gaps between current and targeted performance. In addition to providing evidence of the right direction towards getting out of the gaps (Muchiri, et al., 2011).

The industry 4.0 advent has created an opportunity by considering the huge amount of data being generated on the shop floor and the available emergent Information and Communication Technologies (ICT), e.g., Internet of Things (IoT), big data, machine learning, and cloud computing to use already collected data (Alves, et al., 2020). Likewise, technologies and advanced analytics are seen as key factors that need to be improved for maintenance personnel to make data-driven decisions (Gallo & Santolamazza 2021). Furthermore, taking artificial intelligence and new human-machine interfaces into account, such as virtual and augmented reality technologies, allows the development of smart decision support systems that assist maintenance employees in performing maintenance interventions, lowering maintenance costs, and reducing machine downtime (Alves, et al., 2020).

As stated by Metso, et al. (2018) before applying these technologies and creating a new technological environment, manufacturing companies should focus on the integration of all systems between production and maintenance departments to create a common language. In other words, it is crucial to create an information-sharing culture and related that to utilize a common database with existing systems.

1.2. Problem formulation

The importance of systems and their integration has been a relevant issue for a long time. Galar, et al. (2012) discussed the benefits of having integration between systems in their research. Lee, et al. (2014) discussed service innovation and smart analytics technologies for industry 4.0 and related big data environments in general. Bumblauskas, et al. (2017) explained smart maintenance decision support systems (SMDSS) based on corporate big data analytics. Metso (2018) discussed that information handling and administration, regulation, and control, as well as a shortage of resources, have all been significant issues in maintenance. Alves, et al. (2020) described a system that is about the implementation of a smart and predictive maintenance system for an industrial case study that incorporates technologies to reduce the effects and impact of unexpected production system failures.

In connection with the importance of having integration between systems, some other research mentions the importance of calculating performance indicators (PI), categorization of PIs, and

how to get the concrete results from collected data (Simoes, et al., 2011; Kumar, et al., 2013, Simoes, et al., 2016). Maintenance performance indicators PIs generally help maintenance decisions, such as “what machine to send a technician?”, “who to send to solve a problem?”, “what is the most likely cause of the problem?” (Brundage, et al., 2018). Modern maintenance practices in manufacturing organizations should claim a more tactical and strategic viewpoint, rather than just operational, with a life cycle view based on real-time shop-floor data and cross-functional expertise (Polenghi, et al., 2021). However, there is limited research in the literature about the calculation of machine availability which is defined as one of the most important PIs of maintenance (Muchiri, et al., 2011; Kumar, et al., 2013; Lundgren, et al., 2020).

Although extensive research has been carried out on discovering the importance of having system integration and usage, no single study remains which is about the utilization of existing systems in a manufacturing company that has different systems for different production units. Therefore, this study attempts to show how before having technological applications, manufacturing companies utilize their system integration for existing systems to have the benefit from a common database. Likewise, it is crucial to have common calculations for manufacturing companies to monitor their current situation. Not only that but also this study examines how manufacturing companies can measure one of the most important key performance indicators (KPIs) of maintenance for different production units, which is machine availability.

1.3. Aim and Research questions

The objectives are twofold. The first aim is to explore the influence of system integration within production and maintenance in measuring machine availability. Secondly, to review in detail the procedure of calculating machine availability among several production units in a manufacturing company. To attain this aim, the following research questions are formulated:

RQ1. What are the values of system integration among maintenance and production decisions in measuring machine availability?

RQ2. Which parameters or indicators can be taken into consideration to calculate machine availability among several production units in a manufacturing company?

1.4. Project Limitations

The study was limited in several ways. There are some limitations related to the case company which was chosen for this study. The case company is Scania Industrial Maintenance and relatively Scania AB in the context of a subsidiary. First, the major limitation of this study is the vast amount of production units in different locations in Sweden. The study focused only on the units that are in Södertälje city and it limited the result of this study since there was limited time to compare all production units. Secondly, as the case company has different software and systems for almost all different types of production units, it took time to choose one of these systems to focus on the integration of them with the case company's systems. Relating that limitation, occasionally it was demanding based on time limitations to find the correct contact person to ask questions or to have meetings to understand the operations. When the organizational schemes of the case company and hierarchy of the organization are extensive, it is determined that creating changes in systems takes a long time according to the pecking order strategy of the case company related to the comparison of results. In addition, even though the production system is a combination of machines and people, in this research, the human factor accuracy was excluded due to the limited time. Finally, the lack of detailed provided data that is related to machine availability limits the way of calculating several types of machine availability and adds further caution regarding the generalisability of these findings.

1.5. Thesis Outline

The structure of this paper is divided into the following sections. After the introduction, the paper presents the research methodology. The third part is devoted to the result of the theoretical background by presenting a summary of the current literature on the study topic. The following part presents the result of empirical data, followed by the analysis. Finally, the study is summarized in the conclusion including ideas for future research and implications for academia and practitioners. In the closing part of this paper, references and appendices are presented.

2. RESEARCH METHOD

The following chapter presents the methods which were used for answering the aim and research questions. This includes research design, literature study, and case study which covers data collection including interviews, internal documents, and survey. Thereafter, the selected data analysis method/technique is presented. Lastly, the quality of the research is provided.

2.1. Research Process and Design

To fulfil the research questions which are related to system integration utilization and machine availability calculations, a single case study and literature review were chosen as methods to gain a better understanding of the phenomenon of the study field. A single case study aims to achieve a deep understanding of system integration in manufacturing companies as it has a silent presence with a myriad of advantages in measuring the performance indicators which in turn affect the firm's sustainable growth and success eventually.

Moreover, this study aimed to have an exploratory case study approach to reviewing in detail the available information on the studied case problem and comparing the two ways of literature and practice. An exploratory case study is used to gain a better understanding of the context when few or no previous studies investigate the research questions in depth (Säfsten & Gustavsson 2020).

The research process was backward and forward during the study and the reason for this is because the knowledge acquired from the case company has added the possibility for further exploration in the literature as shown in Figure 1. In addition, an inductive “path of discovery” and a deductive “path of proof” method were used to gain deeper insights that may bring up new or additional interpretations of those correlations already discovered (Säfsten & Gustavsson 2020). To begin, a literature review was conducted to see if system integration and the benefits of using a single database were found to be related from the maintenance perspective (inductive reasoning). Second, the data gathered from the case company was utilized to determine key features associated with the discovered benefits and how they might relate to machine availability calculations (deductive reasoning). To conclude, the overall study has been defined as an abductive approach which means deductive and inductive approaches were well-balanced (Säfsten & Gustavsson 2020).

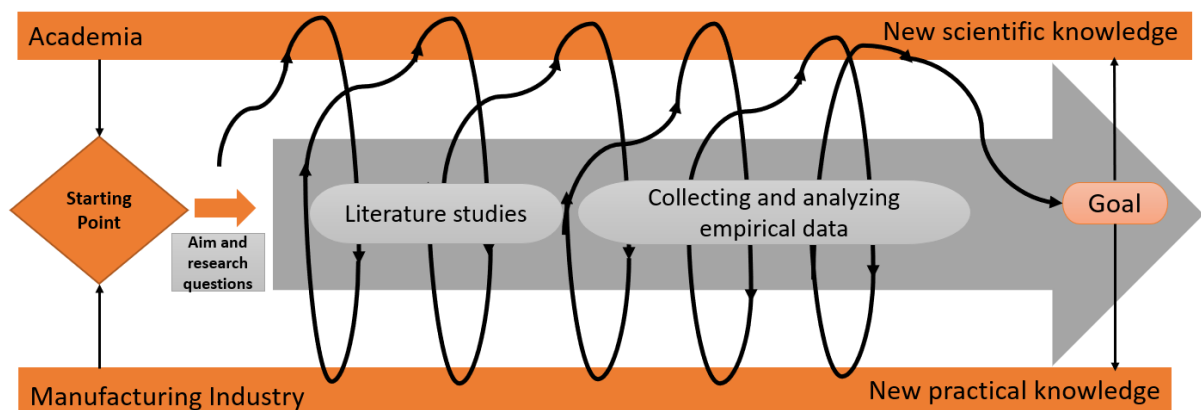


Figure 1: Research Process Fagerström (2004)

The work was firstly started with a pre-study which aimed to brief review to obtain an understanding of the current state and create a roadmap for the study. According to the pre-study, two paths were explored and studied simultaneously. Each path aims to answer each research question. Thereafter, the research questions were integrated into the overall result and analysis to provide a clear picture of the study. The workflow is presented in Figure 2.

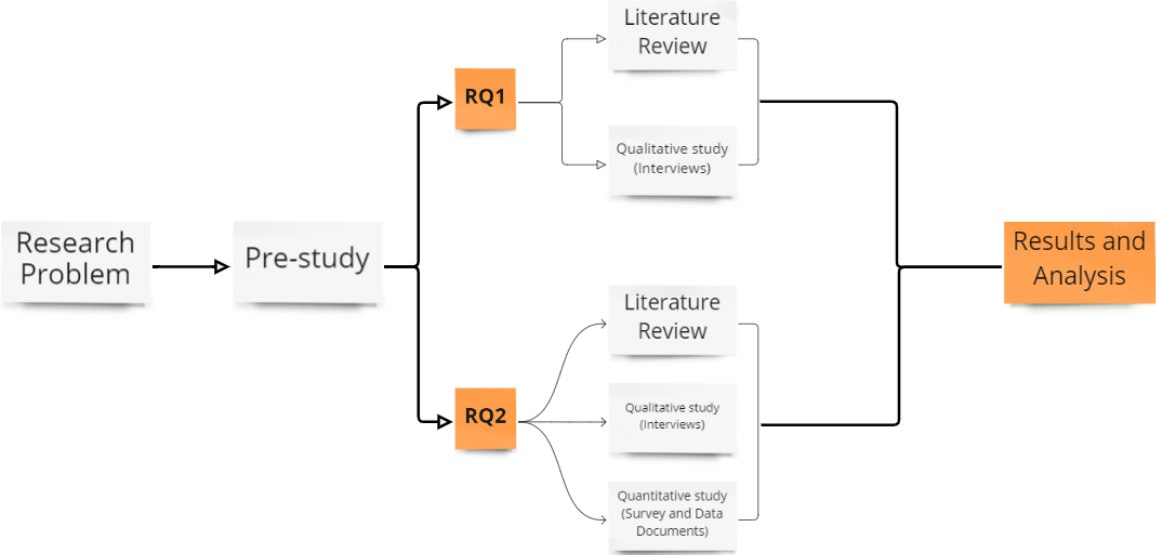


Figure 2: Chronological workflow of the key points in the research

The research methodology was prepared to create a reasonable and applicable result through triangulation, where each research question was triangulated by conducting different methods of data collection to provide answers not depending on only one data point as shown in Figure 2 (Denscombe, 2014). Triangulation is a procedure to examine the results of the same study by conducting different methods of data collection. It allows for improving validity, generating a more in-depth picture of a research problem, and investigating various ways of understanding a research problem (Säfsten & Gustavsson 2020). The triangulation was done by combining both quantitative and qualitative data of the research questions as illustrated in Figure 3.

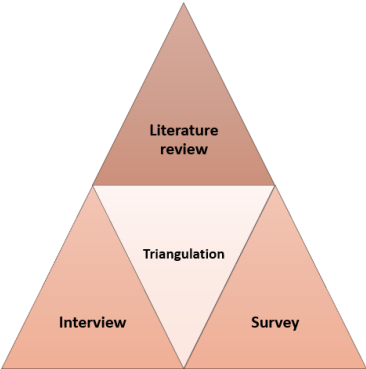


Figure 3: Triangulation methodology

2.1.1. Literature Review

A literature review is an overview method of the previously published works on a specific topic that provides an understanding of existing knowledge in a particular field of research including

theories, key variables, phenomena, and its history (Webster & Watson, 2002; Randolph, 2009). The goal of the literature review is to extract and integrate the data within the study field (Randolph, 2009). In addition, a literature study was conducted to guarantee the theoretical foundation as well as to strengthen the study field (Webster & Watson, 2002). Yin (2018) points out that the literature review aims to broaden sharper and more knowledgeable questions about the topic. Therefore, the literature review combined with the research problem led to the formulation of research questions.

2.1.2. Case study

Yin (2018) explains that case studies capture the complexities of the phenomenon within its real context, particularly when fewer case companies are covered. Therefore, a single case study was adopted to allow a deeper insight into this specific case study of data collection in complex production environments. According to Säfsten and Gustavsson (2020), the following are the advantages of a case study, namely, (1) case study research design involves qualitative and quantitative methods (2) is used to describe, compare, evaluate, and understand different aspects of a research problem (3) is appropriate for this study considering the aim and the research questions that need to be responded to (4) a case study will contribute to a block of concrete and comprehensive knowledge about the real-world subject and investigation of its complex issues (5) it allows a holistic perspective of real-life scenarios.

The case company was selected because of the current challenges it experienced related to data collection in a complex production environment. In addition, the company is willing to change with the aim of achieving its planned strategy. Moreover, the case company has ongoing projects that are planned to be implemented in the early future. Therefore, this case study aimed to create the first step toward further improvements.

2.2. Data Collection

This study has been conducted by using both primary and secondary sources. The primary sources are digital interviews with the company's employees, visits to the company site, and own observations. Books, articles, and the case company's intranet (a private network) have been used as secondary sources. These sources have been chosen as they are the most related to conducting this study.

Table 1 provides an overview of the data collection methods, tools, and techniques that were used to support the result and analysis of the study.

Table 1: Data collection methods

Data Collection Tool	Method	Technique
Literature review	Qualitative	Purposive
In-depth interviews	Qualitative	Snowball
Company database	Qualitative	Random
Survey	Qualitative	Purposive
Data Documents	Quantitative	Purposive

2.2.1. Literature Review

The aim of this literature review was threefold: (a) summarise the existing knowledge that links production and maintenance, information sharing, system integration, and measuring overall performance, (b) provide answers to the research questions; and (c) create a theoretical framework to compare the results of the executed case study with previous research by finding connections, contradictions, and draw conclusions. After the study problem was defined, the

keywords were defined and searched in databases. To select relevant articles, the title, keywords, and abstracts were read. Further, useful articles were logged into an Excel table to analyse later. Moreover, articles were selected and recorded in an Excel table if they are relevant and match the determined following requirements: provide a general description of integration between maintenance and production environment; describe information sharing benefits; explain the benefits of integration on the overall measuring performance. To illustrate, a comprehensive literature review was conducted to combine information obtained from several journals that cover system integration, information sharing, and measuring performance parameters simultaneously. In short, literature reviews harmonize knowledge of a specific field in a qualitative manner (Webster & Watson, 2002). The search engines which were selected for this review were Scopus, ABI/INFORM Global Database, and Google Scholar. Since Scopus is one of the largest databases of peer-reviewed literature, it was used as the primary database to strengthen the validity of the findings. The search engine Google Scholar was used to find a vast number of varied articles that were not approachable through the primary databases. Besides, backward, and forward snowballing were also used as search strategies in order to gather a vast amount of valuable and knowledgeable information that are relevant to this study (Säfsten & Gustavsson 2020). Backward snowballing is generally called "reference tracking" refers to using the reference list of initially selected articles to identify additional papers; whereas forward snowballing as it is generally called "citation tracking" refers to identifying new papers based on those papers citing the paper being selected (Säfsten & Gustavsson 2020).

As described, the usage of books was limited to the methodology section whilst the theoretical framework consists of scientific articles, conference papers, and Swedish standard reports issued by the Swedish standard institute with the vast majority being scientific articles. Search keywords were specified in a preparatory literature review. The chosen keywords were formed by brainstorming and regular discussions among the authors after summarizing the most relevant concepts that describe the field of the study. Table 2 presents the search keywords used in this study.

Table 2: Keywords to search in databases

For maintenance integration	Production and system	For Information sharing	For measuring overall performance
Production system* OR		Information management*OR	Maintenance decision making process* OR
Production development*OR	system	Data management*OR	Maintenance performance indicators*OR
Production integration*OR	system	Data sharing*OR	Maintenance key performance indicators*OR
Production and maintenance system integration*OR		Knowledge sharing*OR	Availability centred maintenance*OR
Computerized maintenance management system* OR		Data driven decision making*OR	Data driven maintenance*OR
Common database*OR		Common database*OR	Maintenance planning*OR
Intelligent manufacturing systems*OR			OEE*OR
Maintenance work order data*OR			
Data collection*AND data integration*OR			
Smart maintenance*OR			

The validity and reliability were ensured by using mostly peer-reviewed articles. When further theories were needed for more in-depth research, new articles were found and added to the theory section. This was an iterative process where the process went back and forth between the new and old information that was either added or deleted.

2.2.2. Case study

To attain the purpose of this study, a combination of qualitative and quantitative data was used. The qualitative data was collected through online semi-structured interviews, visits to the company site, company database, and own observations to analyse and answer the research questions, but also to gain insight into the case company's working way procedures and combine different perspectives (Säfssten & Gustavsson, 2020). The visits were arranged to meet both maintenance and production departments and every department is working with a separate company. The aim of the visits was to gain a better understanding of their daily operation and understand their perspective that is related to system integration as well as having common databases in the future. The in-depth interviews were conducted with employees according to their titles and experiences as shown in Table 3. Further, to sustain a good research quality, the interviews were recorded and transcribed afterward from the recorded audio to ensure the interview's reliability. It was beneficial to gather these interviews since participants refer to other people who they thought would be helpful for this study. This technique is named as "Snowball technique" by Säfssten and Gustavsson (2020). There are three different types of interviews that can be carried out, structured, semi-structured, and unstructured. This study used semi-structured interviews since it is better to ask follow-up questions. Semi-structured interviews were guided with some prepared questions and then developing the questions depending on the respondent. The follow-up questions that were created during the interview depend on what information the respondent would provide and if the information has an aim for the study. Considering that, semi-structured interviews are more flexible this can lead to better results because the interview atmosphere often gets more relaxed (Säfssten & Gustavsson, 2020). In addition, another data collection tool was the company database which can be named intranet in general. From that online portal, general information about the company, their work, organizational scheme, contact person's information were collected.

Table 3: List of interviewed employees

Title	Department
Senior Maintenance Engineer Operations Manager	Maintenance
System Administrator	Maintenance
Software Architect	IT
Lead Software Developer	IT
Data Scientist	DX
Industrial Engineer	DX
Group Manager Production Planning	DT

IS/IT Coordinator	DT
IS/IT Coordinator	DT
Maintenance Group Manager DX	DX Maintenance
Maintenance Engineer	DX Maintenance
Maintenance Engineer	DT Maintenance
Group Manager	DX Maintenance
Group Manager Production Engineering	DX

While the quantitative data was obtained through online file-sharing, emails, and survey. The survey was created using a descriptive survey research strategy, which is a method for learning about a population's attitudes (Forza, 2002). The survey was created online by using Google forms and sent out to the participants who held the position of production unit engineering managers as a web-based survey by direct email to achieve this and to reach out to as wide a portion of the selection group as feasible. To ensure data quality, the survey was pre-tested twice before using it in the normal course of data collection. The interviewees were selected as the people who can reply to the questions related to the topic with the help of the case company. To acquire a representative outcome, it is critical to get responses from as many segment groups as feasible. This allows researchers to make assumptions about the remainder of the group if there is a need (Denscombe, 2014). To keep questions relevant for the participants, the questions were slightly modified based on which role and shop or department they were in. For several questions, respondents were given a five-point scale and asked to select the option on the scale that best represented their thoughts. The Likert scale is a five-point scale that allows participants to choose from the following options: "strongly agree, agree, neutral, disagree, strongly disagree" (Denscombe, 2014). The scale was employed to make the data easier to analyse and compare. Open-ended questions were added to learn more about the thoughts related to the interviewee's production units. The survey covered all possible related questions that support the specific studied case in the way of calculating the machine availability and identifying the gaps in calculating with the purpose of standardizing the calculations. The survey questions are presented in Appendix 1.

2.3. Data Analysis

In this section the selected data analysis method and technique for literature review and case study were presented.

2.3.1. Literature Review

The thematic analysis approach was the method selected for analysing the literature data. Thematic analysis is used in the qualitative research method for systematically identifying,

organizing, analyzing, and reporting repeated patterns (themes) across a dataset within the research topic. It allows a deeper insight into collective meanings across qualitative data (Säfssten & Gustavsson, 2020). The organized steps were derived from Säfssten and Gustavsson (2020, p.212). First, the authors prepared a template through an Excel Table where to write the most interesting and relevant findings of the articles that could be used in the study (See Table 4 – Categorization of articles). Second, the fundamental themes (e.g., systems integration, common database between production and maintenance, information sharing, performance indicators) were outlined and summarized in excel. Third, similarities were sorted together using an online whiteboard tool named Miro for creative and convenient brainstorming. Fourth, the selected themes were linked to the formulated research questions and the results were collected. Moreover, regular discussions were conducted in between these steps to guarantee the work quality.

Table 4: Categorization of Articles

Categories used for Analysis of Articles in Excel Sheet
Year of the Article
Article Name
Peer reviewed (Yes/No)
Name of Journal
Type (Literature review, Case study, etc.)
Purpose of Study
Keywords
Research Questions
Definitions
Conclusion
How can used in report? (For introduction, for method, etc.)

2.3.2. Case Study

Once all data had been collected from the case company, a thematic analysis approach was conducted for identifying and interpreting patterns of meaning across qualitative data. To analyse the data from the interviews, all the transcription of the interviews were read, notes were taken, and the key concepts that were related to the company's current problem were highlighted and patterned in a shared file. These concepts were reviewed, discussed, and linked to concepts gathered from the theoretic framework to obtain further concrete results.

Data was gathered from the intranet at various time points during the study were written in a shared file, discussed, and afterward, a relevant combination of the data gained from the interviews and online portal was patterned together with the aim for further outcomes.

In terms of the survey, 4 answers out of 12 have been received. Data analysis started with reading the received responses, identifying the differences, and logging into an excel sheet. Further, the advantages of using Google forms support the data analysis. Google Forms enable storage and organizing of the results in a spreadsheet with Google Sheets. Each row features the responses from each respondent, and each column features a question from the prepared form. Thereafter, calculations and figures have been created. Validation of the results was done with the contact person from the case company. The results of the study were presented through online meetings where the results were discussed followed by a written report where the results were analysed by using figures and different calculations. The company representative agreed with the overall structure of the findings.

2.4. Quality of the research

Validity and reliability are terms used to check out the scientific quality of academic research and are used to evaluate the quality of research (Säfsten & Gustavsson, 2020). To ensure that, both critical and impartial approach were taken as well as support from the supervisor and company contact person which contributed to reliability and ensured validity. In addition, for ensuring validity, most articles were originated from journals, conference papers, and standard reports that were peer-reviewed. Moreover, to assure the quality of the study, a structured framework (Figure 4) as suggested by Säfsten and Gustavsson (2020) was followed. In addition, the way of conducting the literature review added good dependability and ensure that the results of this study are consistent, which also contribute to increasing the reliability. In addition, the literature review research method aimed to increase the quality of the study since for the academic community, the literature review research method supports theory development and distinguishes knowledge gaps to be filled, hence contributing to knowledge improvement (Webster & Watson, 2002). According to o Säfsten and Gustavsson (2020), the review of the levels of knowledge can also be precious for individuals and organizations outside academia, since it may support individuals in a profession as well as support well-founded decision-making in companies.

Lastly, triangulation was used which means that multiple data collection methods and sources were utilized to ensure that different methods or observers of the same phenomenon generate the same results. Furthermore, this has been done to attain deepening understanding of the research problem to increase credibility and validity of the results.

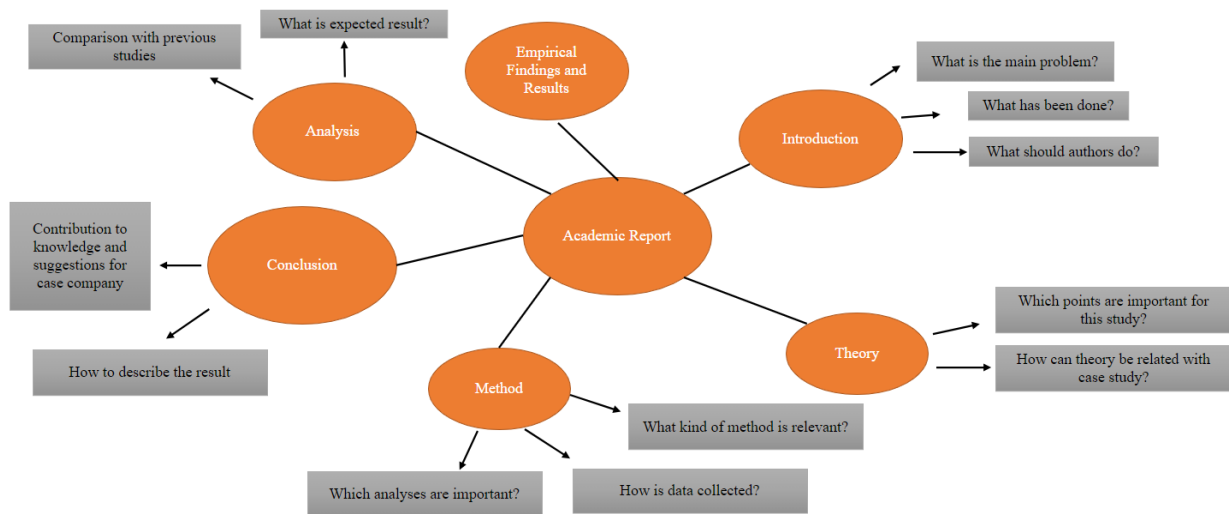


Figure 4: The road map within questions which were asked during writing (Säfsten & Gustavsson, 2020)

3. THEORETIC FRAMEWORK

A comprehensive literature review has been performed to understand the positive impact of system integration, information sharing and its impact in measuring performance parameters that are related to maintenance and production functions in manufacturing companies.

3.1. Production systems in manufacturing industry

Superior production system capabilities are widely recognized as critical for competitive success (Bruch & Rösiö, 2015). To remain competitive, production systems must be capable of handling rising demands appropriately and efficiently (Bellgran & Säfsten, 2010). Correspondingly, a production system aids manufacturers in their pursuit of a faster time to market, a smoother production ramp-up, increased customer acceptance of new products, and/or a stronger proprietary position (Pisano, 1997). The required production output is obtained through a high level of availability, which is depending on the reliability of the equipment and maintainability, and maintenance supportability (CEN, 2011).

According to Bruch and Rösiö (2015), a production system is complex, and it includes more than just the machining equipment. It necessitates clear communication between the material handling system, employees, the information system required to coordinate and regulate all components and the technological system. Therefore, a production system's elements are meant to be interconnected, share information, make decentralized decisions, and act independently (Lundgren, et al., 2020). Specifically, manufacturing execution systems (MES) were created with the goal of assisting humans in making decisions relating to manufacturing operations management. This is accomplished using MES, which makes real-time access to production data possible. Additionally manufacturing companies need production data to satisfy future market expectations for product variety and faster delivery (Mantravadi, et al., 2020).

To find a solution for complexity of production systems, many industries have benefited from the advancements of the Internet, IoT, big data, cloud computing, artificial intelligence (AI), and other next generation information technologies (New IT) (Tao & Qi, 2019). As more physical things become connected to the Internet on the Internet of Everything (IOE) era, a vast volume of data is captured by smart devices and transmitted through the IoT. Mobile Internet, social networking, e-commerce, and other Internet applications have dramatically expanded the Internet's applications. As a result, many types of data are fast growing in popularity. Decisions are increasingly being made based on data and analysis, rather than on experience, across a variety of businesses (Qi & Tao, 2018).

3.1.1. Information sharing

The essential data in a technology-driven production ecosystem are generally gathered from a variety of sources, including environmental data, performance data, condition monitoring data, and production data (Metso, 2018). Accordingly, more sophisticated business models and collaboration patterns are possible due to the growing number of stakeholders and departments involved in value creation and access to a vast amount of data (Metso & Kans, 2017). On the other hand, it should be taking into consideration that due to a lack of communication between people, companies, and the technical system, the networking trend and the massive amount of data might result in fragmented data (Candell, et al., 2009; Ranasinghe, et al., 2011).

By making extensive and creative use of relevant data, shared big data can produce new value, such as optimizing maintenance and operations and extending asset lifetime. For example, the

service provider can assist decision makers by collecting high-quality data from a variety of sources, recognizing patterns in the data, and developing new and superior analyses based on the combined data. Manufacturing companies' ability and motivation to establish a single platform are hampered by the usage of various systems (Metso, 2018).

Sjödín, et al. (2018) recommend that the data collection procedure should be updated and disseminated throughout the production cycle. When insights are conveyed concurrently with all relevant stakeholders in the appropriate forum and at the appropriate degree of abstraction, transparency is achieved. As a result, firms must create cross-functional digitalization networks to facilitate rapid information transfer. To promote the development of enhanced data management techniques and processes that allow for efficient storage and usage of the expanding amount of production data being collected, models should be designed for structured data gathering and sharing (Metso, 2018).

3.1.2. System Integration

Integration of information systems ensures that data and information are complete (Polenghi, et al., 2021). In an equivalent way, information and data integration is primarily concerned with the technical issue of allowing systems to communicate with one another to establish architectures or platforms, resulting in interoperability issues (Bokrantz, et al. 2017).

System integration and its relationship with integration is extensively discussed in literature. According to Frishammar and Hörte (2005), a company's ability to effectively integrate cross-functional operations is built on the process of sharing information to identify and solve problems (Moenaert & Souder, 1990; Turkulainen, 2008). In the same way, the processing of relevant and necessary information between functionally specialized departments is required in an integration process (Frishammar & Hörte, 2005; Swink, et al., 2007). Not only but also integration problems are frequently caused by a lack of symmetry in information or an inability to communicate the necessary data (Turkulainen, 2008). To put it another way, information exchange is "the major mechanism that allows individuals to become connected," as Moenaert and Souder (1990, p.98) define it and this definition is still relevant as stated by Bokrantz, et al. (2020) as integration refers to the cross-functional collaboration with all aspects of organization.

Integration of systems are categorized as vertical and horizontal integration (Li, et al., 2019). While vertical integration refers to the company's flexible and reconfigurable systems, as well as the degree to which they are fully integrated with one another to achieve agility; horizontal integration is concerned with the integration of partners (Erboz, 2017). Wang, et al. (2016) starts to explain the importance of vertical integration as actuator and sensor, control, production management, manufacturing, and corporate planning are some of the physical and informational subsystems that a factory has. Furthermore, to enable a flexible and adaptable manufacturing system, vertical integration of actuator and sensor signals across several levels is critical, all the way up to the enterprise resource planning (ERP) level. The smart machines constitute a self-organized system that can dynamically reconfigure to adapt to new product types of thanks to vertical integration, and vast data is collected and analyzed to make the manufacturing process transparent. At the same time, many other linked corporations should compete and cooperate with one corporation. Related firms can establish an efficient ecosystem through horizontal inter-corporation integration. Information, money, and materials can all flow freely between these businesses. As a result, new value networks and business models could arise (Wang, et al., 2016).

3.2. Industrial Maintenance

Maintenance has always been thought of as a function that fixes equipment. This is reflected in the EN 13306 standard, which defines maintenance as follows: “the combination of all technical, 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 can perform a required function” (CEN, 2001). Another standard IEC 62264-3 defines maintenance operations management as “the collection of activities which coordinate, direct and track the functions that maintain the equipment, tools and related assets to ensure their availability for manufacturing and ensure scheduling for reactive, periodic, preventative, or proactive maintenance”. Indeed, maintenance enables a company to maintain its production system running smoothly and to deliver products of the needed quality (Franciosi, et al., 2020).

Maintenance systems are critical in industrial manufacturing environments, which are frequently described as stochastic, dynamic, and chaotic. The occurrence of unexpected disturbances causes a degradation of system performance, resulting in the loss of productivity and business opportunities, both of which are critical roles in achieving competitiveness (Cachada, et al., 2018). Production volume and expenses, asset performance, equipment availability, and product quality are all affected by maintenance (Franciosi, et al., 2020). Furthermore, because of its impact on both productivity, safety and quality, maintenance is critical to a manufacturing company's success (Miształ, et al., 2014). Similarly, maintenance management in an industrial plant connects many organizational business functions and operations, its implementation is difficult and time-consuming (Silvestri, et al., 2020).

According to Cachada, et al. (2018) the first type of maintenance used in the past was corrective or reactive maintenance, which was driven by the "run-to-fail" philosophy. With time, the focus shifted to failure prevention rather than correction, resulting in the establishment of preventive maintenance (Silvestri, et al., 2020). Both pre-determined and condition-based maintenance are included in this category. Predictive maintenance is a subclass of condition-based maintenance that is considered its evolution because it is focused on the prediction and prevention of failure or degradation. More proactive maintenance concepts have recently been introduced, utilizing management tools and strategies based on ICTs. These concepts consider the possibility of adapting activities to dynamic changes in the environment and aligning them to business strategies and external requirements throughout the system's life cycle (Guillén López, et al., 2018). When it comes to work planning and maintenance scheduling, aspects such as labour availability, inventory and stock management, and compatibility with production planning must all be considered (Santolamazza, et al., 2018).

3.2.1. Computerized maintenance management system (CMMS)

The earlier development of CMMS is given to Labib in 1998 developed a maintenance program to facilitate control machine performance and execute suited methods that help to repair, minimize, and avoid failures (Shankar, et al., 2021). During the industrial revolution, information has been known as a significant resource that improves maintenance function. To clarify, information is a set of data recordings that is transferred to a receiver who uses it to create decisions (Laudon, et al., 2000). Companies have seen information as a strong weapon that has a pivotal role in effective coordination between all employees (Lopes, et al., 2016). Thus, information systems arose with computer science and consist of many operations from the field of information technologies to organizational activities, namely usage of methods to determine user necessities and relevant solutions (Laudon, et al., 2000). Information system to maintain maintenance functions is called as CMMS (Lopes, et al., 2016). Therefore, the attention towards

using the CMMS has increased significantly in controlling the maintenance management in servicing and producing sectors (Jamkhaneh, et al., 2018). A CMMS is a software tool designed to assist maintenance strategy based on an information system in terms of planning, scheduling, managing, and monitoring maintenance operations related to machine, equipment, or other facilities and services (Tretten & Karim, 2014; Lopes, et al., 2016; Jamkhaneh, et al., 2018).

According to Tretten and Karim (2014), the benefit of the CMMS is not only as a control tool for maintenance activities but also, it is to guarantee a high standard of outputs quality by implementing sufficient maintenance activities in the long run considerable amount of literature has been published on the benefit of CMMS implementation. Likewise, Wienker, et al. (2016), hold the view that the implementation of the CMMS will synergize efficient communication which in turn enhances planning and scheduling, immediate access to the historical records, and the creation of high-quality reports based on the perfect database. Shankar, et al. (2021) assert that CMMS can help in cost reduction associated with spare parts and maintenance activities and improved productivity for both service and manufacturing providers. Moreover, a CMMS software program controls the maintenance information and data of resources in centralized storage as well as monitors the work processing and tracking the maintenance activities through the asset management life cycle. Even so, a CMMS with an unsuitable designed user interface (UI) can result in work user error and user mistakes (Tretten & Karim, 2014). For this reason, CMMS must be modifiable and flexible because of the company's uniqueness (Shankar, et al., 2021).

3.3. Performance Measurement in Manufacturing Industry

Sayings like “It is not possible to manage what you cannot control, and you cannot control what you cannot measure!” Peter Drucker (Weber & Thomas, 2005, p.3) emphasize the importance of measuring performance parameters. Several authors (Kennerley & Neely, 2003; Rouse & Putterill, 2003; Lundgren, et al., 2020), point out the significance of identifying the performance measures to evaluate the current state performance to close the identified gaps and reach the desired performance which in turn will affect on company's growth.

Paradigm shifts such as globalization have altered the environment of manufacturing industries and imposed the need for adaptation by integrating various measurement systems to evaluate the performance of manufacturing operation activities by using the PMS to sustain their existence. According to Kang, et al. (2016), within a PMS, the strategical objectives are first determined according to the enterprise's desires to achieve. Afterward, each goal is supported by a set of detailed indicators allowing to accomplish the strategic goals. Such indicators are referred to as KPIs which are defined as a set of quantitative and strategic measurements in a PMS that indicate the significant success factors of the industry (Kang, et al., 2016). According to the reports of International Standard ISO 22400–1 (2014) and International Standard ISO 22400–2 (2014), KPIs play a vital role in understanding and enhancing manufacturing system functioning. To effectively utilize the usage of KPIs for continuous improvement (CI) or managing production, understanding the relationship between them is essential for a wide range of improvements since the distinct characteristics of performance are not independent and cannot be considered separately from each other, KPIs also have mutual affection. Some KPIs may be positively or negatively interconnected (Kang, et al., 2016).

Performance consists of five dimensions: cost, productivity, time, flexibility, and quality (De Toni & Tonchia, 2001). For a manufacturing industrial company and a production system, effectiveness can be characterized as generating the planned outcome whereas efficiency refers

to producing the product with the minimum waste of time, cost, and effort while providing a given level of customer satisfaction. i.e., to what extent the resources are effectively utilized. Performance measurement in a manufacturing company is not dependent on one individual PI but in fact on a pattern of multiple and well-defined PIs (Ravelomanantsoa, et al., 2019; Lundgren, et al., 2020). The relationship between PIs is not separate but interrelated with each other. Therefore, a well-defined knowledge of this relationship can lead to more advantageous results and establish actions based on the right decisions (Rodriguez, et al., 2009; Kang, et al., 2016).

Neely, et al. (2000) propose five elements to take into consideration during the PIs creation: measure the right variables, create right calculations of the PIs, compare the PIs to previous outcomes for further improvement, compare the PIs with other competitors PIs to enable benchmarking, to have long-run objectives to evaluate the direction in consideration of these objectives. As Neely and Bourne (2000, p.6) write that “the trick is to measure as little as possible but to ensure that you are measuring the things that matter”. However, the direction of several companies is to increase the number of PIs which in turn will result in challenges of analyzing data and measuring (Tangen, 2005; Salloum, 2013; Parida, et al., 2015). This might be clarified by the dynamics in companies and new development strategies without changing the performance measurement (Salloum, 2013).

3.4. Maintenance performance indicators

Organizations have been considered the perspective of maintenance performance differently: cost, budget performance, and availability from the perspective of economists, senior management, and the production department, respectively (Pintelon & Van Puyvelde, 1997). However, the classical view of maintenance organizations is to fix the equipment (Ylipää, et al., 2017). This has led to focus on PIs which explain the behaviour of machine failure (internal efficiency), instead of focusing on the system level (external efficiency). Maintenance performance covers the internal and external efficiency of the maintenance action. Nevertheless, the manufacturing industry uses all PIs that are associated with the internal efficiency of maintenance (Parida & Kumar, 2006).

In the literature of maintenance PIs, the difference is defined in terms of “leading” and “lagging” indicators (Muchiri, et al., 2011; Smith & Mobley, 2011; Kumar, et al., 2013). Leading indicators are input-oriented activities performed during the maintenance process, for example, preventive maintenance (PM) duties carried out in relation to planned PM tasks; while lagging indicators are output-oriented to measure the results of those activities, namely, for example, mean time to failure (MTTF), mean time to Repair (MTTR), and direct maintenance costs (Kumar, et al., 2013; Lundgren, et al., 2020). Together the maintenance process (leading) indicators and maintenance results (lagging) indicators are crucial for controlling performance measurements of maintenance functions due to their influence (Muchiri, et al., 2011; Lundgren, et al., 2020).

In a literature review of maintenance performance measurement, Simoes, et al. (2011) identify 345 several PIs. The main 37 PIs were identified, with a condition that they should be repeated at least twice in the investigated literature. The main PIs are availability, cost, quality, overall equipment effectiveness (OEE), MTBF, MTTR, downtime, and productivity. Parida and Chattopadhyay (2007) categorize the maintenance PI into seven categories. The PIs are distributed into equipment-related indicators, maintenance task-related indicators, cost-related indicators, impact on customer satisfaction, learning and growth, health, safety, security, and

environment (HSSE), and employee satisfaction. As stated by EN 15341:2019 some of maintenance indicators measure the technical performances of the properties (e.g., safety, availability, reliability, maintainability, etc.) and can be viewed at different levels (portfolio of plants, plant, system, subsystem, equipment, components). Further indications measure immediately the performances of the maintenance sub-processes (preventive maintenance process, corrective maintenance process, spare part provisioning process, human maintenance resources process, etc.).

Muchiri, et al. (2011) state the effects of good indicators as assisting in identifying the performance gaps, helping in performance monitoring and control, supporting knowledge and further improvement, supporting maintenance functions to achieve the set objectives, and contributing attention to maintenance actions that create change on the manufacturing performance. A series of PIs are used to measure the performance of a manufacturing company rather than a single PI. These PIs are not self-contained, as they are frequently linked. The use of PIs will be more useful if companies are aware of these relationships, as it will give companies a better grasp of the process and make them more likely to make the appropriate judgments (Rodriguez, et al., 2009; Kang, et al., 2016). Equally, through the MPM, companies can understand the value added by maintenance, review, and modify their maintenance strategies, understand the impacts of maintenance on other functions and stakeholders as well as on health and safety, etc. (Parida & Kumar, 2006)

According to EN 15341:2019 KPI of the maintenance actions are frequently implemented in all the physical assets either industrial, infrastructures or civil buildings or transportation systems, etc. The goals of these indicators should be applied to (a) evaluate the status; (b) compare (internal and external benchmarks); (c) determine (analysis of strengths and weaknesses); (d) specify objectives and define targets to be reached; (e) design improvement actions; (f) frequent measurement of changes over time. Typically, these indicators can be applied:

- At regular time intervals, as an illustration by preparing and following up on a budget, during the evaluation of the performance, comparing results in several ways: budgeted, expected, predicted, planned, actual, etc.
- On a spot basis, as for instance within the structure of audits, studies, and/or benchmarking.

In addition to that, the period to be addressed for measurement be dependent on the organization's policy, aims, and time constants of measured phenomena; it can be day, week, month, quarter, semester, year, etc. The KPIs can be often measured as a proportion between factors (numerator and denominator) measuring the operations, assets, or events, according to a specified method, but can also be the result of the quantitative or qualitative questionnaire. The numerical values, the qualitative and the quantitative data to calculate each KPI shall be gathered and developed according to available approaches and techniques of common industrial accounting and definite managerial accounting rules applied to the maintenance function. These indicators are used to calculate any qualitative or quantitative properties of an item or the process to create a homogeneous base to compare and establish future objectives to achieve and improve.

3.4.1. Maintenance process leading indicator

The vital aim of maintenance leading indicators is to evaluate and control whether the planned tasks are carried out as expected for the purpose of attain the desired production outcomes. However, the maintenance process is considered by identified work procedures (based on maintenance goals and performance gaps), work preparations, work timing, and work implementation. Also, the key performance indicators for each process are intended to measure

how well the requirements of each process are utilized (Muchiri, et al., 2011; Kumar, et al., 2013; Lundgren, et al., 2020).

3.4.2. Maintenance results lagging indicators

The purpose of lagging indicators is to measure the results of maintenance processes terms of equipment performance and maintenance cost. Consequently, maintenance seeks to meet the planned goals at an optimal cost, and it is necessary to measure the cost effectiveness of the performed maintenance activities. Therefore, the results elements of the maintenance process have been summarized as availability, reliability, and operability of the technical systems. Further, maintenance strives to consider these elements and therefore prove the successful of maintenance processes (Muchiri, et al., 2011; Kumar, et al., 2013; Lundgren, et al., 2020).

3.4.3. Availability

Measurement is recognized as a powerful tool that assists to understand the overall manufacturing performance. Maintenance measurement is a major valuable key in the context of a competitive environment as it provides useful insights into how to control and improve the maintenance process (Raza, et al., 2016). RAMS product characteristics refer to Reliability, Availability, Maintainability, and Maintenance Supportability which is known as a decision-making tool that is used to optimize the maintenance strategy, identify how to increase the availability of the system, and thus increase the overall profit as well as reduce the life cycle costs (Markeset & Kumar, 2001). Table 5 presents the Swedish standard definitions of RAMS.

Table 5: Swedish standard definitions of RAMS

Concept	Definition	Reference
Availability	Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided	SS-EN 13306,2001 SS-EN_13306, 2017
Reliability	Ability of an item to perform a required function under given conditions for a given time interval.	SS-EN 13306,2001 SS-EN_13306, 2017
Maintainability	Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.	SS-EN 13306,2001 SS-EN_13306, 2017
Maintenance supportability	Ability of a maintenance organization of having the right maintenance support at the necessary place to perform the required maintenance activity at a given instant time or during a given time interval.	SS-EN 13306,2001 SS-EN_13306, 2017

The availability can be described in quantitative terms, and it is measured in percentage (0-1) and is thus influenced by the other three factors of RAMS characteristics, namely, reliability,

maintainability, and maintenance supportability. Together, the reliability and maintainability of an item are closely related to the construction of a product or a system whereas the maintenance supportability relates to the organization and how the maintenance department is designed and organized the work. In short, all factors need to strive for a successful outcome to obtain a high availability (Bengtsson & Salonen, 2007).

As stated by Bengtsson and Salonen (2007) in the report, to calculate the availability performance, four equations as shown in Table 6 might be used depending on what specific availability the company wants to address.

Table 6: Availability calculations from literature

Availability Name	Availability Formula	Definition
Inherent Availability	$A_k = A_i = \frac{MTBF}{MTBF + MTTR}$	MTBF: Mean time between failure MTTR: Mean time to Repair
Achieved Availability	$A_m = A_a = \frac{MTBM}{MTBM + \bar{M}}$	MTBM: Mean time between maintenance \bar{M} : Mean maintenance time
Operational Availability	$A_o = \frac{MTBM}{MTBM + MDT}$	MDT: Mean downtime
Overall Equipment Efficiency (OEE)	Availability x Performance rate x Quality rate	Availability in OEE = $\frac{\text{Planned production time} - \text{stop time}}{\text{Planned production time}}$

The amount of production time lost due to failures, changeovers, adjustments, and other sorts of downtime is measured by availability in OEE (Bamber, et al., 2003). The quota between actual operative time and planned, available operative time is the unit of measurement. This term is based on scheduled available production time, which differs from theoretically available production time. This is a concern, according to Bamber, et al. (2003), because planned maintenance, for example, is not considered a loss. This indicates that there is no motivation to rationalize preventive maintenance. On the other hand, according to Ljungberg (1998), availability should be estimated using the whole calendar period, or 8760 hours of available production time each year.

3.5. Smart Maintenance

Companies have become intelligent and smart because of the implementation of Industry 4.0 technologies (Zolotová, et al., 2018). New concepts such as digitalization, IoT and Cyber Physical Systems (CPS) have acquired prominence throughout industries, including manufacturing, because of technological advancement. In other words, with the help of these concepts, Industry 4.0 will play a key role in transforming traditional businesses into Smart Factories (Erboz, 2017). The main pillars of Industry 4.0 are classified as shown in Table 7.

Table 7: The main 9 pillars of Industry 4.0 and explanation (Erboz, 2017)

Main Pillars of Industry 4.0	Definition
1. Industrial Internet of Things (IIoT)	Connection of physical objects and systems.
2. Big Data and Analytics	Large datasets are used for analysis and decision making.
3. Simulation	Mathematical models and algorithms are used for optimization processes.
4. Cloud Computing	Platforms are shared with multiple users.

5. Augmented Reality (AR)	Human – machine interaction within technology based on combination of 3 dimensional (3D) virtual objects and real 3D environment.
6. Additive Manufacturing	3D printing technology.
7. Autonomous Robots	Robots can solve complex tasks.
8. Cyber Security	Protection of shared data.
9. Horizontal and vertical system integration	Integration inside of companies and other business partners.

Maintenance is being pushed to adopt Industry 4.0-like solutions (Zheng, et al., 2018) by refocusing attention on diagnostic and predictive tools (Herterich, et al., 2015; Lee, et al., 2015) for data-driven design improvements and services (Tao, et al., 2018). Some technologies can be easily implemented in maintenance departments. For example, IIoT is a technology that allows physical things to communicate with each other through the internet for global or local data exchange (Alqahtani, et al., 2019; Karkalos, et al., 2019; Olaf & Hanser, 2019). These CPS are the technology drivers for effective organizational collaboration. CPSs provide efficient communication among all actors using multiple sensory input and output devices with the goal of achieving common goals (Roy, et al., 2016; Dinardo, et al., 2018). According to Silvestri, et al. (2020) CPSs have a significant impact on manufacturing industrial services. These communication technologies are especially important for maintenance, as they improve efficiency and quality. The CPS's ability to predict and initiate service actions, as well as remote diagnostic, is a direct explanation. Furthermore, CPSs enable the collection of a large amount of real-time data about the present state of machines, which serves as the foundation for big data analysis (Peres, et al., 2018), which is a major support for maintenance planning. For example, Ooijevaar, et al. (2019) offer a study in which portable vibration sensors are used to monitor bearing and gear states utilizing wireless data transfer and diagnostic algorithms.

According to Yan, et al. (2017), industrial big data analytics will provide various benefits, including near-zero downtime, predictive maintenance, and more. Simulation is a computer tool that aids in the design of manufacturing systems and allows for efficient maintenance. In value networks and real-time data optimization from intelligent systems, simulation is used (Chong, et al., 2018). Cloud computing is a technology that allows users to share processing resources and other devices on demand (Hassan, 2011; Zolotová, et al., 2018). It is also feasible to transfer information between systems from a manufacturing line to the entire plant using cloud technology (Marilungo, et al., 2017), as well as perform offsite analysis (Tao, et al., 2018). As a result, the scalability and adaptability of intelligent manufacturing systems can be improved (Chen, et al., 2018).

Similarly, the adoption of IIoT, system integration, and, to a lesser extent, cloud computing is critical to carry out most maintenance activities more efficiently. Big data analytics and simulation are commonly utilized to improve existing practices or allow for the creation of more sophisticated maintenance plans, whereas pillars like Augmented reality and autonomous robotics are commonly used in support procedures (Silvestri, et al., 2020).

Giliyana, et al. (2022) worked with eleven large manufacturing companies in their study to see if they have already implemented any type of smart maintenance technology, if they did, in what context were these technologies implemented. Furthermore, they explored if any values were added to the maintenance organization, challenges, opportunities, benefits, and disadvantages of these implemented smart maintenance technologies. The questions related to the given ext were

asked to manufacturing companies and concluded that the empirical findings reveal various additional benefits, such as fewer unplanned stops and fewer production disruptions, real-time condition monitoring, failure prediction at an earlier stage, timely corrective maintenance, and so forth.

4. RESULT (Empirics)

The fourth chapter presents the empirical findings of the case company. Firstly, a description of the case company is presented. Afterward, the empirical results from interviews, survey, observations, and case company internal recourses are provided.

4.1. Case Company – Scania

Scania is a member of the Traton Group. Scania, MAN, Volkswagen Caminhões e Ônibus, and Navistar all operate closely together under this umbrella. Scania is a world-leading producer of transportation solutions, including heavy-duty trucks and buses, as well as a comprehensive product-related service offering. Scania provides vehicle financing, insurance, and rental services so that their customers may focus on what they do best. Scania also specializes in power solutions for industrial and marine applications.

The products of Scania are basically classified as trucks, busses and coaches, power solutions and services. The company's focus areas are sustainability, electrification, digitalization, and China. The Core Values of the company are listed as a customer first, respect for the individual, elimination of waste, determination, team spirit, and integrity.

Scania's sales and service network, with 54,000 workers in over 100 countries, is strategically located where clients need them, no matter where they operate. Most of the company's research and development efforts take place in Södertälje, Sweden. Manufacturing takes place in Europe, Latin America, and Asia, with capabilities for worldwide component and vehicle interchange. In Africa, Asia, and Eurasia, the corporation also maintains regional product centres. In 2022, a new manufacturing plant will be established in China.

Scania Production System (SPS) provides the company with a shared style of thinking so that they can accomplish the greatest potential results as a team. The production system is built on the organization's common values, concepts, and processes, which outline how the company should conduct operations in a cost-effective and long-term manner. The production system provides a common language for the firm. It helps to define the company and learn about the difficulties they encounter in a way that everyone can understand - no matter where employees are in the organization or where they are in the world. SPS also serves as a shared plan for future issues, allowing people to work more effectively and provide better results. Above all, when everyone sees the big vision, the task becomes more joyful. They frequently utilize the SPS house to demonstrate how the many components of the manufacturing system are linked. The production system, like a building, is constructed from the ground up. The company's ideals and leadership serve as the cornerstone. The house's walls, floors, and roof are the principles. They all rely on one another and must be in place for the house to function properly.

Scania has global units within production and logistics (P&L) all around the world. The list of global units:

- Transmission Assembly (DT) – Södertälje, Sweden
- Battery Production (ME) – Södertälje, Sweden
- Chassis Assembly (MS) – Södertälje, Sweden
- Chassis Assembly Zwolle – Zwolle, Netherlands
- Cummins Scania XPI (DI) – Södertälje, Sweden
- Engine Manufacturing (DM) – Södertälje, Sweden
- Engine Assembly (DE) – Södertälje, Sweden

- Industrial Maintenance (SIM) – Södertälje, Sweden
- Logistics Centre Netherlands
- Logistics Centre Sweden
- Painted Parts Meppel – Netherlands
- Product Introduction Chassis and Cab (MP) – Södertälje, Sweden
- Production Angers – France
- Production Lahti – Finland
- Production Ferruform – Luleå, Sweden
- Production Oskarshamn – Oskarshamn, Sweden
- Production Slupsk – Slupsk, Poland
- Scania Latin America – Brazil
- Transmission Manufacturing (DX) – Södertälje, Sweden

4.1.1. Scania in Sweden

Scania Sverige AB is a distributor for Scania's products and services in Sweden. Scania Sweden has five dealerships of its own with 22 workshops in the metropolitan regions of Stockholm, Malmö, and Gothenburg as well as Uppland, Gävleborg and Dalarna. In Sweden there are 15 private retailers with a total of 63 workshops around the country.

- Four of the Swedish retailers also sell buses.
- There are seven marine and industrial engine workshops.
- There are 1,800 employees in Sweden, of which 1,000 are service technicians.
- There are 1,000 workshop workspaces for service and repairs.
- There are 32,000 Scania trucks/buses in traffic in Sweden.

4.1.2. Scania Industrial Maintenance (SIM)

The Board of Directors formulates and decides the company's emphasis, which includes its vision, business model, long-term goals, and tactics. Scania Industrial Maintenance's (SIM) job as a company is therefore to meet the organization's objectives while adhering to the established strategy. SIM accomplishes this by concentrating its efforts on a few key areas, or focus areas, as well as breaking down goals and planning and implementing actions in the various operations. It is crucial to mention that SIM is a subsidiary for Scania AB, means that SIM is different company than Scania AB.

SIM's long-term success is contingent on everyone recognizing and adhering to the same set of beliefs and principles. SIM's strategy plan serves as a foundation for meeting client needs while increasing profitability, growth, and competitiveness. SIM has a long-term perspective in focus on Scania. SIM strives for efficient flows that are tailored to the needs of the customer. When employees participate in workplace development and understand why and how they progress, the job becomes more enjoyable.

SIM is responsible for the maintenance of equipment, real estate, systems, and media in the short and long term. SIM oversees machine purchase and conversions, as well as maintenance delivery. SIM operates residues with a high level of supply consistency and cost effectiveness. SIM is designed in such a way that it is both safe and cost-effective to achieve the desired machine availability. SIM has established a future strategic plan which explained the company's present situation, outlines the future plans, and shows how the company can reach the desired goals. The plan has four success factors, namely, people & plant, customers, growth & transformation, customers, and profitability & flow. This strategic plan is known as a structural system that contains essential helpful strategies (leadership, SPS, Global Maintenance,

Processes, Teamwork). Each component of the system is critical and can create a significant influence. Thus, a weak element weakens the whole system. Thus, the plan is to establish a well-structured foundation enable the company to identify the work gaps and solve the problem creatively to achieve the future targeted term which is world class maintenance.

4.1.3. Scania Information Systems

The architecture of information systems is based on the hierarchical on Enterprise-Control System Integration (ANSI/ISA-95) or ISA-95 as it is more generally called, it is an international standard from the international society of automation for developing an automated user interface between enterprise and systems for controlling as well as ownership of the relevant data. The objectives of ISA-95 are to provide stable terminology that is a foundation for manufacturer and supplier communication, it offers symmetric information models and provides consistent operations models which are the fundament for clarifying application usefulness and how information is to be used efficiently. ISA-95 integrates the layers model of technology and business process for manufacturing enterprises as levels for the standard.

In fact, the five levels of ISA-95 are implemented in the Scania production facility and each level can be seen based on a software perspective followed by the lowest tier, the infrastructure level. These levels are shown in Figure 5:

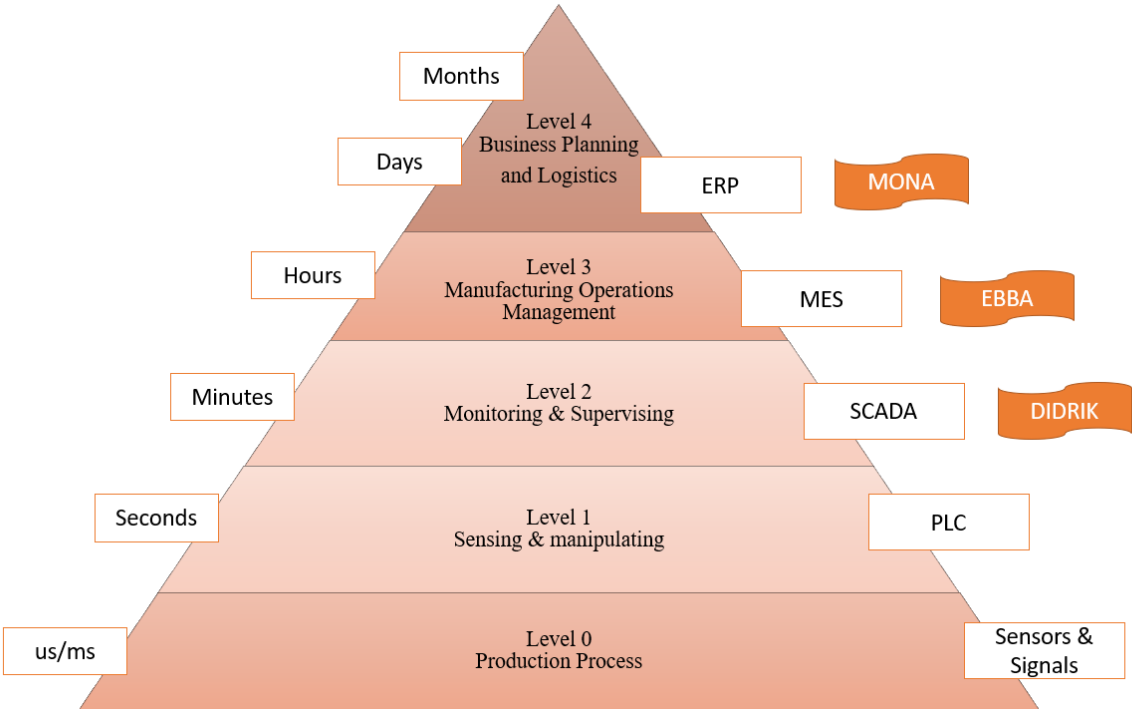


Figure 5: ISA-95 Levels

4.1.3.1. Mona

ERP on the top level (the so-called Mona at Scania). Mona is an ERP system, which is particularly used for the coordination of production order planning, material handling, and assembly production processes. It is the initial starting point of production. Mona contains of four different modules to support the local processes in a common way for all global Scania production units. The current production system architecture below Mona system is called the Production Information Systems Architecture (PISA) which is an internal standard for information systems at Scania’s production level. PISA consists of Ebba and Didrik.

4.1.3.2. Ebba

MES on the next secondary tier (the so-called Ebba at Scania). Ebba is Scania's own name for the information technology (IT) solution that support the everyday activities on the shop floors at Scania. There are a few different names that are used for this system. MOM, MES, Apriso or Ebba are usually used, MOM (Manufacturing Operations Management) or MES are the domain names which is used by the general industry. Apriso is the MOM/MES product platform name which is sold by Dassault Systems. And finally, Ebba is the name Scania choose as the customisation of MES as a product for Shopfloor IT. The following areas are currently included in Ebba:

- Production process: Production preparation, planning, order handling, product quality, process overview, work instruction execution, report extraction.
- Quality process: Deviation management, quality control.
- Logistics process: Delivery planning, picking, material transport, report extraction.
- Maintenance process: Maintenance planning and execution.
- Reporting of financial transactions to Mona (approved and rejections).
- Traceability and containment.

Currently, DT, DE, DM, DX, DL production units which are in Södertälje use Ebba as MES. But also, there are other production unit locations like Oskarshamn, Netherlands, Latin America partly use Ebba for their daily planning operations.

Even though there is more than one way of working in different production units, Scania decided to use and roll out Ebba system in all production units and the implementation is in progress. The reasons for selecting Ebba to implement within all company for MES were:

- High capabilities of Ebba related to production, quality, logistics, and maintenance processes. Therefore, it will enable improving quality management and control.
- Increased visibility and efficiency as it provides dashboards with relevant information about what is happening in real-time as well as Ebba is an important data source for the reports visualized in Power BI.
- The company and its employees have knowledge and skills development about the Ebba system.
- Integration between different systems like Mona ERP system which enables information and sharing.

4.1.3.3. Didrik

The third tier is the supervisory control and data acquisition (SCADA) system (the so-called Didrik at Scania). Didrik is a developed system of SCADA for interconnecting production equipment in various production environments to realize tacting, traceability, and production follow-up in a standardized way. The Didrik system is based on Programmable Logic Controller (PLC) and SCADA technology to provide an open system that is easy to adapt and integrate into different types of production equipment. In addition, Didrik is used in the production assembly area for monitoring and controlling the production line to verify that the product is produced based on the specified demanding requirements that fulfils customer satisfaction.

4.1.3.4. Maximo

Maximo is a CMMS system of Scania. It supports the inventory and purchase of Non-Automotive Products, as well as the maintenance of buildings and machines at Scania. The system is used in all of Scania's production units. Service requests, creating, preparing, and assigning of work orders to technicians, scrapping of equipment and placement, moving of construction objects, connect spare parts to an inventory, moving equipment between facilities

and related these activities some reports are available in that system. Also, preventive maintenance information and operations are accessible in Maximo.

4.1.3.5. PowerBI

Power BI is a business intelligence analytics service provided by Microsoft. Power BI platform provides nontechnical business users with tools for aggregating, analysing, visualizing, and sharing data. Power BI is a suite of business analytics tool that deliver insights throughout an Enterprise or organization. Scania has chosen Power BI as their strategic choice for creating BI reports. The tool is well suited for self-service and has been developed from Excel and Power Pivot. Further, it provides interactive visualizations with self-service business intelligence capabilities where end users can create reports and dashboards by themselves, without having to depend on IT staff or database administrators. At present, the information from Ebba is visualized through reports built in Power BI for production units.

4.1.3.6. Data Lake

Data Lake is a big data repository that contains data in its native format until it is needed. Data Lake is implemented in the open-source framework which also enables the processing needed for advanced business analytics. The collection and storage instances of various data assets support Scania to be more data driven. These assets are stored in a near-exact, or even exact, copy of the source format and are in addition to the originating data stores, empowering improved quality, richness, and analytics of the data. To clarify, the aim is to pour all the data into Data Lake and visualize the needed information to deliver a continuous, personalized customer and user experience.

4.1.3.7. Relation Between Information Systems at Scania

At Scania, there are some integrations between multiple systems at various levels and production units. There is a project underway to implement Ebba (MES) system in all production units, as well as to integrate this system with a shared database called Data Lake in the future. According to the product owners of Ebba system, at the present time, there are limited data for some production units from Ebba in Data Lake and the future target is to connect all data into Data Lake to take an advantage of having common databases among production and maintenance departments particularly, and other departments generally. However, this integration is technically possible to implement but also it requires plenty of time as well as top management decisions.

The interviewees at SIM reported that there is a need to see the data from PRUs to have data driven decisions about the crucial KPIs of maintenance because there are assumed numbers today to measure availability regarding total planned production time context in SIM systems (24 hours 7 days). Since SIM gives service to Scania AB, there is a need to create a common language about numbers and KPIs which are calculated by two sides of maintenance activities. It is understood that if it is possible to create a common database, it will be easier for both SIM and Scania AB to see the same data which are more reliable according to Ebba system. This common database can be the first step to building a common language. Within the case company's strategic plan, a collaborative foundation, time-related issues in data collection, integration processes, and activities into a system are all considered critical elements of information integration that can predict and control all maintenance-related information.

Data Lake is a common database in Scania. Currently, there is a direct integration between Maximo (CMMS) which SIM uses and Data Lake. Also, other departments can enter their manual data to Data Lake to share within the company. At present, except for some production

units, there is an indirect and not-completed integration between Ebba for production units (PRU) and Data Lake. The integration information is visualized in Figure 6.

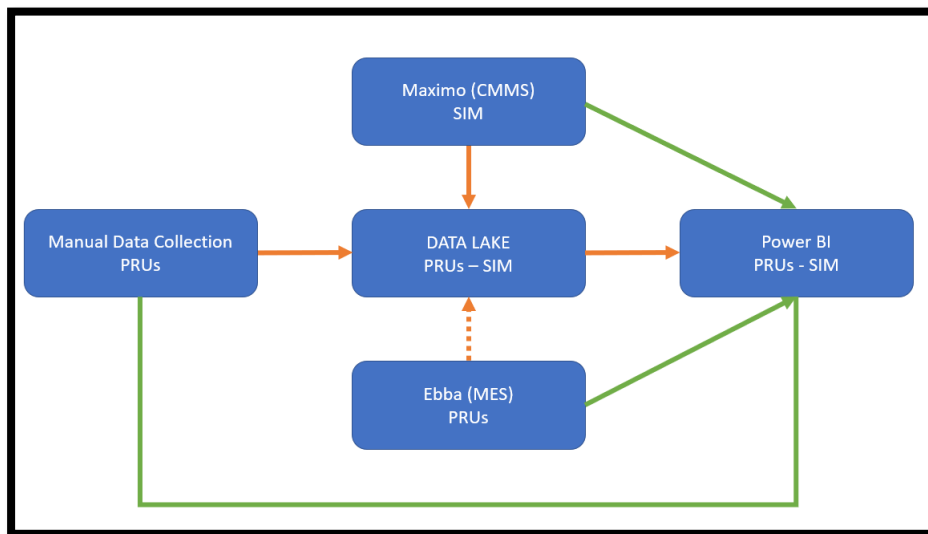


Figure 6: Connection between information systems at Scania

Power BI is a tool that Scania uses for reporting. Also, PowerBI has a connection with Maximo (CMMS) for maintenance reporting and Ebba (MES) for PRUs reporting. Likewise, it is possible to create reports within manual data collection from PRUs in PowerBI.

4.2. Way of working in different production units at Scania

Scania has various production units all around the world. With the help of meetings from different departments, it was defined and learnt that almost all production units have their own way of working. Likewise, production planning system, data collection system and even reporting types are different for each production unit. According to time limitation, it was not possible to look all production units' way of working. Therefore, DT and DX production units were selected since they are in Södertälje, and they have already implemented Ebba system in their daily operations in order to have contribution to this study.

It is crucial to mention in this point that, these production units do not calculate availability as mentioned earlier. Instead, for production units, it is critical to plan shifts of workers rather than plan production time and calculate machine availability. These production units generally plan their shifts yearly. Within meetings, it is understood that machine availability should be calculated by maintenance department by having shift data from production units.

In that section, way of workings of DT and DX production units, systems they use, and calculations of availability information are given. It is agreed with the production units that, planned shift time can be used instead of planned production time.

4.2.1. Way of working of DT

DT is a production unit that refers to the transmission assembly. This production unit classify their production operations as axles assembly, e-mobility, and gearbox assembly. The logistics operations are classified as production planning, material planning, logistics development (operation and project based) and material handling. Engineering is categorized as process and engineering improvement groups.

Generally, production planning schedules are not changed during the year since it is not easy to change all workers' working time, the quantity of produced products, and preventive maintenance time.

The production planning shift decision is determined based on the product type. Special Axle and Eline products work one shift while Rear Axle, Central Gear, and Gearbox products work two shifts. The total working hours are varied according to the product type and weekday. In Table 8, the detailed information is given related to days, and different departments.

Table 8: Total planned production time according to shift tables at DT

Days	Central gear	Eline	Gearbox	Rear Axle	Special Axle
Monday	14:42	07:30	14:56	14:41	07:30
Tuesday	14:20	07:10	14:33	14:19	07:30
Wednesday	14:42	07:30	14:56	14:41	07:10
Thursday	14:42	07:30	14:56	14:41	07:30
Friday	10:59	07:30	11:05	10:46	07:30

For DT, there was a specific need to choose at least two different products to calculate availability. Therefore, with the help of maintenance engineers at DT, Gearbox (DТОGP) and DТОAM (Rear Axle) products were selected. Another reason to select these products was that the manual registered down time information was relatively more reliable rather than other products according to maintenance engineers who work with at DT. Related with that selection, Gearbox and Rear Axle shifts were taken into consideration to compare the real machine availability and assumed machine availability.

4.2.2. Way of working of DX

DX is a production unit that refers to transmission manufacturing. The engineering operations categorized as advanced engineering, manufacturing, industrial engineering, process technology, and prototype and low series manufacturing. Global manufacturing - capacity sourcing is classified as capacity sourcing and sourcing process steps. Logistics operations are grouped as material handling, production planning, material planning and logistics development.

Production planning works with:

- Planning of both production and deliveries. The goal is to deliver components according to customer demand at the lowest cost.
- Balances the assembly mix for production lines including pre-assemblies and material-picking if needed.
- Active sequencing to optimize the production sequence. In the event of a disturbance, it is handled any sequence changes and re-plan production and/or delivery.
- Sets temporary restrictions, if necessary, for example, based on material availability and machine capacity.
- Delivery planning to meet customer needs and optimize the filling rate in transport.

In the DX production unit, there are different types of shifts for different production lines. Generally, it differs from 3 to 4 shifts regarding the line in DX which is shown in pictures 3 and 4. This planning is done through an Excel sheet, then entered Ebba system and shared within all production units. Also, production planning is completed with week details for a year. According to planning schedule which can be seen in Picture 3 and Picture 4, the DX production unit does not have any detailed information about the stoppages like breaks or meetings.

Arbetsstidsart 3 - Intermittent 3-skift, 37, 53h per vecka																																
2022 FM: Mån-Fre 06.00-14.12 EM: Mån-Tors 14.00-23.12 Natt: Mån-Fre 23.00-06.12																																
Fre 14.00-20.00														Nattskiftet redovisas på den dag arbetspasset startar.																		
Januari			Februari			Mars			April			Maj			Juni																	
V	DAG	1	2	3	V	DAG	1	2	3	V	DAG	1	2	3	V	DAG	1	2	3	V	DAG	1	2	3	V	DAG	1	2	3			
52	1	Lör			1	Tis	E	N	F	1	Tis	N	F	E	13	1	Fre	F	E	17	1	Sön			1	Ons	F	E	N			
	2	Sön			2	Ons	E	N	F	2	Ons	N	F	E	14	2	Lör			18	2	Mån	N	F	E	2	Tor	F	E	N		
	3	Mån	F	E	N	3	Tor	F	E	3	Tor	N	F	E	15	3	Sön			19	3	Tis	N	F	E	22	3	Fre	F	E	N	
	4	Tis	F	E	N	4	Fre	F	E	4	Fre	N	F	E	16	4	Mån	N	F	E	20	4	Ons	N	F	E	4	Lör				
	5	Ons	F	E	N	5	Lör			5	Lör			17	5	Tis	E	N	F	21	5	Tor	N	F	E	5	Sön					
	6	Tor	F	E	N	6	Sön			6	Sön			18	6	Ons	E	N	F	22	6	Fre	F	E	6	Mån	N	F	E			
	7	Fre	F	E	N	7	Mån	N	F	E	7	Mån	F	E	N	14	7	Tor	F	E	23	7	Lör			7	Tis	E	N	F		
	8	Lör			8	Tis	N	F	E	8	Tis	F	E	N	15	8	Fre	F	E	24	8	Sön			8	Ons	E	N	F			
	9	Sön			9	Ons	N	F	E	9	Ons	F	E	N	16	9	Lör			25	9	Mån	F	E	N	9	Tor	F	E	N		
	10	Mån	E	N	F	10	Tor	N	F	E	10	Tor	F	E	N	17	10	Sön			26	10	Tis	F	E	N	10	Fre	E	N	F	
	11	Tis	E	N	F	11	Fre	F	E	N	11	Fre	F	E	N	18	11	Mån	N	F	27	11	Ons	F	E	N	11	Lör				
	12	Ons	E	N	F	12	Lör			12	Lör			19	12	Tis	N	F	E	28	12	Ons	N	F	E	12	Sön					
	13	Tor	E	N	F	13	Sön			13	Sön			20	13	Ons	N	F	E	29	13	Fre	F	E	13	Mån	N	F	E			
	14	Fre	E	N	F	14	Mån	F	E	N	14	Mån	E	N	F	15	14	Tor	F	E	30	14	Lör			14	Tis	N	F	E		
	15	Lör			15	Tis	E	N	F	15	Tis	F	E	N	16	15	Fre	F	E	31	15	Sön			15	Ons	N	F	E			
	16	Sön			16	Ons	E	N	F	16	Ons	E	N	F	17	16	Lör			1	16	Mån	E	N	F	16	Tor	N	F	E		
	17	Mån	N	F	E	17	Tor	F	E	N	17	Tor	F	E	N	18	17	Sön			2	17	Tis	E	N	F	17	Fre	F	E	N	
	18	Tis	N	F	E	18	Fre	F	E	N	18	Fre	E	N	F	19	18	Mån	N	F	3	18	Ons	E	N	F	18	Lör				
	19	Ons	N	F	E	19	Lör			19	Lör			20	19	Tis	F	E	N	4	19	Ons	E	N	F	19	Sön					
	20	Tor	N	F	E	20	Sön			20	Sön			21	20	Ons	F	E	N	5	20	Fre	F	E	N	20	Mån	F	E	N		
	21	Fre	F	E	N	21	Mån	N	F	E	21	Mån	N	F	E	22	21	Tor	F	E	6	21	Lör			21	Tis	F	E	N		
	22	Lör			22	Tis	E	N	F	22	Tis	N	F	E	23	22	Fre	F	E	7	22	Sön			22	Ons	F	E	N			
	23	Sön			23	Ons	N	F	E	23	Ons	N	F	E	24	23	Lör			8	23	Mån	N	F	E	23	Tor	F	E	N		
	24	Mån	F	E	N	24	Tor	N	F	E	24	Tor	N	F	E	25	24	Sön			9	24	Tis	N	F	24	Fre	F	E	N		
	25	Tis	F	E	N	25	Fre	F	E	N	25	Fre	F	E	N	10	25	Mån	E	N	F	10	25	Ons	N	F	25	Lör				
	26	Ons	F	E	N	26	Lör			26	Lör			11	26	Tis	N	F	E	11	26	Ons	F	E	N	26	Sön					
	27	Tor	F	E	N	27	Sön			27	Sön			12	27	Ons	E	N	F	12	27	Fre	F	E	N	27	Mån	E	N	F		
	28	Fre	F	E	N	28	Mån	N	F	E	28	Mån	F	E	N	13	28	Tor	F	E	13	28	Lör			28	Tis	E	N	F		
	29	Lör			29	Tis	F	E	N	29	Tis	F	E	N	14	29	Fre	F	E	14	29	Sön			29	Ons	E	N	F			
	30	Sön			30	Ons	F	E	N	30	Ons	F	E	N	15	30	Lör			15	30	Mån	F	E	N	30	Tor	F	E	N		
5	31	Mån	E	N	F	31	Tor	F	E	N	31	Tor	F	E	N	16	31	Ons	E	N	16	31	Tis	F	E	N						

Picture 3: Example from 3 shifts planned production

Arbetsstidsart 4 - Kontinuerligt 4-skift utan storhelgsdrift, 36,0 h per vecka																																				
2022 FM:Mån-Tor:06.00-14.24 EM:Mån-Tor:14.12-22.42 Natt: Må-Fr=22.30-06.12 Helg: H1=Fr=14.48-00.00 H3=So=12.30-22.12 Fr=06.00-15.00 So=22.00-06.12																																				
Fre 14.00-20.00														Nattskiftet redovisas på den dag arbetspasset startar.																						
Januari			Februari			Mars			April			Maj			Juni																					
V	DAG	1	2	3	4	V	DAG	1	2	3	4	V	DAG	1	2	3	4	V	DAG	1	2	3	4	V	DAG	1	2	3	4							
52	1	Lör				1	Tis	E	F	N		1	Tis	E	F	N		13	1	Fre	F	E	H1	17	1	Sön	N	E	F	N	1	Ons	E	F	N	
	2	Sön			H3	2	Ons	E	F	N		2	Ons	E	F	N		14	2	Lör			H2	18	2	Mån	N	E	F	N	2	Tor	F	E	N	
	3	Mån	E	F	N	3	Tor	F	E	N		3	Tor	F	E	N		15	3	Sön			H3	19	3	Tis	N	E	F	N	22	3	Fre	H1	F	
	4	Tis	E	F	N	4	Fre	F	E	N	H1	4	Fre	F	E	N	H1	16	4	Mån	N	E	F	20	4	Ons	E	F	N	4	Lör	H2				
	5	Ons	E	F	N	5	Lör			H2	5	Lör			H2	17	5	Tis	N	E	F	21	5	Tor	F	E	N	5	Sön	H3						
	6	Tor	F	E	N	6	Sön			H3	6	Sön			H3	18	6	Ons	E	F	N	22	6	Fre	H1	F		6	Mån	N	E	F				
	7	Fre	F	E	N	7	Mån	N	E	F	14	7	Tor	F	E	N	14	7	Lör			H2	23	7	Tis	N	E	F	7	Ons	N	E	F			
	8	Lör			H3	8	Tis	N	E	F	15	8	Fre	H1	F		15	8	Ons	E	F	N	24	8	Ons	E	F	N	8	Tor	F	E	N			
	9	Sön			H3	9	Ons	E	F	N	16	9	Lör			H2	16	9	Mån	N	E	F	25	9	Mån	N	E	F	9	Tor	N	E	F			
	10	Mån	N	E	F	10	Tor	F	E	N	17	10	Tis	N	E	F	17	10	Tis	N	E	F	26	10	Tis	N	E	F	10	Fre	H1	F				
	11	Tis	N	E	F	11	Fre	H1	F		18	11	Fre	H1	F		18	11	Ons	E	F	N	27	11	Ons	E	F	N	11	Lör	H2					
	12	Ons	E	F	N	12	Lör	H2		19	12	Lör	H2		19	12	Tor	F	E	N	28	12	Tor	F	E	N	12	Sön	H3	N						
	13	Tor	F	E	N	13	Sön	H3	N	20	13	Sön	H3	N	20	13	Ons	N	F	E	29	13	Fre	H1	F		13	Mån	F	N	E					
	14	Fre	H1	F		14	Mån	N	E	F	21	14	Mån	N	E	F	21	14	Tor	F	E	N	30	14	Lör	H2		14	Tis	F	N	E				
	15	Lör	H2		15	Tis	N	E	F	22	15	Tis	N	E	F	22	15	Fre	F	E	N	31	15	Sön	H3	N	15	Ons	F	N	E					
	16	Sön	H3	N	16	Ons	N	F	E	23	16	Ons	N	F	E	23	16	Lör			1	16	Mån	F	N	E	16	Tor	F	N	E					
	17	Mån	N	E	F	17	Tor	F	E	N	24	17	Tor	F	E	N	24	17	Sön			2	17	Tis	F	N	E	17	Fre	F	H1					
	18	Tis	N	E	F	18	Fre	H1	F		25	18	Fre	H1	F		25	18	Ons	F	N	E	3	18	Ons	F	N	E	18	Lör	H2					
	19	Ons	N	E	F	19	Lör	H2		26	19	Lör	H2		26	19	Tor	F	E	N	4	19	Tor	F	E	N	19	Sön	H3	N						
	20	Tor	N	E	F	20	Sön	H3	N	27	20	Sön	H3	N	27	20	Ons	F	N	E	5	20	Fre	F	H1		20	Mån	E	F	N					
	21	Fre	H1	F		21	Mån	N	E	F	28	21	Mån	N	E	F	28	21	Tor	F	N	6	21	Lör	H2		21	Tis	N	E	F	N				
	22	Lör	H2		22	Tis	N	E	F	29	22	Tis	N	E	F	29	22	Fre	F	H1	7	22	Sön	H3	N	22	Ons	F	N	E						
	23	Sön	H3	N	23	Ons	F	N	E	30	23	Ons	F	N	E	30	23	Lör	H2		8	23	Mån	E	F	N	23	Tor	F	E	N					
	24	Mån	F	N	E	24	Fre	H1	F		31	24	Fre	H1	F		31	24	Sön			9	24	Tis	N	E	F	24	Fre	F	E	N				
	25	Tis	F	N	E	25	Fre	F	H1		1	25	Fre	F	H1		1	25	Mån	N	E	F	10	25	Ons	E	F	N	25	Lör						
	26	Ons	F	N	E	26	Lör	H2		2	26	Lör	H2		2	26	Tis	N	E	F	11	26	Ons	F	N	E	26	Sön	N	E	F					
	27	Tor	F	N	E	27	Sön	H3	N	3	27	Sön	H3	N	3	27	Ons	E	F	N	12	27	Fre	F	H1		27	Mån	N	E	F					
	28	Fre	F	H1		28	Mån	N	E	F	4	28	Mån	N	E	F	4	28	Tor	F	N	13	28	Lör	H2		28	Tis	N	E	F	N				
	29	Lör	H2		29	Tis	N	E	F	5	29	Tis	N	E	F	5	29	Fre	F	H1	14	29	Sön	H3	N	29	Ons	E	F	N						
	30	Sön	H3	N	30	Ons	E	F																												

4 shifts	24	24	24	24	24	9.5	11.5	141
----------	----	----	----	----	----	-----	------	-----

For DX, there was a specific need to choose at least two different shifts to calculate machine availability. Therefore, with the help of maintenance engineers at DX SV15383 / Shot Peening with 4 shifts and AVD4649 Carbon Sync production lines with 3 shifts were selected. Another reason to select these shifts was that the manual registered down time information was relatively more reliable rather than other products regarding to maintenance engineers who work at DX.

4.3. Survey

The survey has been sent to 12 managers in different production units in Södertälje. Four of the contacts answered the survey (see Table 10 for attendees' information).

A variety of perspectives were expressed for the same question, and this sheds light on opinions that differed due to not having one standard formula to apply. Three themes emerged from the answers, (1) the production environment considers the machine availability as a maintenance individual issue, and (2) a common view amongst interviewees was that there is no one commonly used system for calculating machine availability; each production unit has a different system and therefore, no standard formula is applied for calculation machine availability (3) contradiction between the term availability and Overall Process Effectiveness (OPE).

Table 10: Respondents of survey

Production Unit Full Name + Abbreviation	Contact Person - Title
Battery Production	Industrial Engineering Manager
DI	Manager Production and Project Engineering
DE	Industrial engineering manager
DF Foundry	Production Manager

Questions related to machine availability were asked in order (See Appendix 1 for questions). Respondents answered the definition of machine availability for their production units, then gave points related to calculation of machine availability from 1 to 5 (from less important to most important) and gave information related the machine availability calculations in their production units. The respondent who said "no calculations" defined the reason of not calculating as "We have not started our production yet, only prototype and small-scale production of old products, we are ongoing to set up all parameters for production supervision. It will be done later in our project/organisation development" (See Table 11).

Table 11: Questions and answers related to current calculations of machine availability

How do you define machine availability?	Calculation of machine availability is...	In your production unit, do you calculate machine availability?
Time when the machine is technically OK for production to use it.	5	No
Uptime in the machine	4	Yes
high uptime, stable, easy to maintain	5	Yes

Equipment ready and accessible for production.	4	Yes
--	---	-----

When the topic had been changed to the responsible person of calculating, the system is used and the way of calculating machine availability, the questions were given in Table 12.

Table 12: Responsible person, system, and formula of calculation.

If there is a calculation of machine availability, who is the responsible person of this calculation? (If you are not the responsible, please write the name of contact person)	If there is a calculation of machine availability, which system do you use to get the required data?	If there is a calculation of machine availability, how do you calculate?
We do not have it but I believe it is industrial engineering that is responsible for the evaluation and analysis done to keep track of potential improvements	Not yet, but it will be Ebba and PowerBI in combination (I could not choose two answers in the alternatives)	No calculation
Production Engineer	Manual data collection	We use OPE calculation.
maintenance	I don't know which system is used.	Experience sharing
Production Engineer	Manual data collection	In the question before we lack response options. We use FOQUS for the calculation.

The following questions were related to way of calculation of machine availability in Table 13.

Table 13: Details of calculating machine availability

If there is a calculation of machine availability, please select your type of calculation.	If there is a calculation of machine availability, do you think it is the correct way of calculation?	If there is a calculation of machine availability, do you make some assumptions while calculating?
No calculation but I miss the answer total machine for one line (serial connection between machines in one line)	No calculation	No calculation
Both each machine and full	Yes	NO
For each machine in each line	Yes	many small disturbances or few long. to decide what actions to take
For each machine in each line	Yes	Off course. We make a lot of assumptions. The OPE/OEE standard at Scania make many assumptions.

Following questions were related to problems if they have ever faced (Table 14).

Table 14: Problems of calculating machine availability

If there is a calculation of machine availability, do you face any problems?	If you face any problems with calculation, please specify these problems
No calculation	
No problems with calculation	
Yes, there are some problems	always a person who write the input, it would be great to use the machine itself to report its problems
I don't know	

For future calculations, the following questions were asked (Table 15). It was important to discover what different production units think about the calculation of machine availability for KPIs. Respondents gave points from 1 to 5 (from less important to most important) and gave their suggested formula, which was the most crucial part to discover, and explanations for these suggestions were provided.

Table 15: Future suggestions for calculating machine availability

Do you think that machine availability is a necessary KPI for production units?	What is your suggested formula of standardized machine availability calculation for all production units?	Please explain the reason of suggesting this formula
5	(Planned production time - Technical losses) /Planned production time). Not to be mixed with OPE that is: (approved parts x Cycle time) / Planned production time	It is defined from an overall perspective and should be used so we can compare the figures between different units. (SPS global office)
4	OPE	It's a common way of doing it
5	connected equipment, use data from source,	info put in one time
5	Just follow the industry standard	One standard for all

5. ANALYSIS

The fifth chapter presents analysis of the study. Firstly, general analysis of study is presented. Afterward, the analysis of research questions is provided. Finally, availability calculations in different production units are shown.

5.1. General Analysis

This study set out to explore the influence of system integration within production and maintenance in measuring machine availability. In addition to review in detail the procedure of calculating machine availability among several production units in a manufacturing company.

One unanticipated finding was related to the ongoing project of implementing and rolling out Ebba system in all production units to be used in the daily operations work. Therefore, the study solely focused on Ebba system because of this project. This result may be explained by the fact that Ebba system becomes a common system that has several benefits which help in solving the posed problems. This result supports the idea of system integration as Ebba system is capable to store the required data and therefore, integrating it to Data Lake where employees can access and extract the needed data easily. As shown in Picture 5 it is possible to put data from Ebba to Data Lake.

The screenshot shows the SCANIA Databases in Data Lake interface. At the top, there are summary statistics: 2 Total Databases, 1 Table Count, 44 Total Columns, and 44 Total Comments. The date is 2022-02-16 12:15. The interface is divided into several sections:

- db_name:** A list of databases with checkboxes. 'ebba' is selected.
- Table Name:** A list of tables with checkboxes. 'time' is selected.
- Column Name:** A list of columns with checkboxes. 'Sök' is selected.
- Comment:** A table listing the selected column 'Sök' and its comment: 'Sök'.
- Column Name:** A table listing all columns for the selected table 'time' and their comments.

db_name	Table Name	Column Name	Comment
ebba	time	Sök	Sök
ebba_dt			
ebba_mm			
ebba_dm			
ebba_dx			

Column Name	comment (col)
active	Indicates if the record is active or deleted
archiveid	The archive identifier
createdby	The user who created the record
createdon	The date the record was created
datalake_import	Import time from source database
endtime	The end time of the day schedule.
id	The ID of the performance record.
lastarchivedby	The user who last archived the record
lastarchiveon	The date the record was last archived
lastdeletedby	The user who last deleted the record
lastdeleteon	The date the record was last deleted
lastreactivatedby	The user who last reactivated the record
lastreactiveon	The date the record was last reactivated
lastrestoredby	The user who last restored the record from archive
lastrestoreon	The date the record was last restored from archive
lastupdatedby	The user which last updated the record
lastupdateon	The date when the record was last updated
referenceid	Links to FlexData
rowversionstamp	Current version identifier for the row, for detection of concurrency violations
starttime	The start time of the day schedule.
totalhours	The total hours of the day schedule.
workspaceid	The foreign key to the DB_WORKSPACEID Enable delete cascade.

Picture 5: The current data tables in Data Lake from Ebba

As a result, this observation has helped in the selection of the production units. The current study concentrates on DX and DT production units for the following reasons (1) They start to use Ebba system to plan their daily production; (2) The process of communication and correspondence is rather easy with these two production units; (3) They have provided a sample of data to evaluate the difference between the current and future states. Another unanticipated finding was related to the under-way project which aims to integrate Ebba system into Data Lake. The implementation of this project will also support the result of the present study of having common databases which aim to provide a fully integrated platform to ensure the data availability for true reliability-based maintenance schedule optimization.

The expectations of maintenance key performance indicators are broader than in the traditional view of maintenance objectives. To clarify, organizations have been considered the perspective of maintenance performance differently: cost, budget performance, and availability from the perspective of economists, senior management, and the production department, respectively (Pintelon & Van Puyvelde, 1997). However, this study evaluated the measure of equipment performance which is called availability as it is considered an important KPI and is one of RAMS characteristics (Markeset & Kumar, 2001). Availability is defined according to SS-EN 13306, (2001); SS-EN_13306, (2017) as "*Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided*". Since SIM's strategic plan is to reach world-class maintenance, the goal is to establish a solid infrastructure for solving the basic problems and be ready for further improvements. Within the strategic plan, the focus is on ensuring the equipment's availability as it provides enough production run time to generate profit. As a result, machine availability is essential for a successful manufacturing plant (CEN, 2011).

5.2. Analysis of RQ1

An initial objective of the project was to answer the question *What are the values of system integration among maintenance and production decisions in measuring machine availability?* The findings from this study make several contributions to the current literature. *First, this study investigated the association between production and maintenance departments.* As mentioned in the literature review, production and maintenance planning are dependent to a significant extent on each other (Schreiber, et al., 2019). For instance, the findings of Franciosi, et al. (2020) indicate that maintenance allows a company to keep its production system running and deliver products with high quality. Correspondingly, production output, asset performance, equipment availability, and product quality are all affected by maintenance (Franciosi, et al., 2020). Prior studies that have also noted the importance of improving the system integration between production and maintenance environments can also be found (Algabroun, et al., 2017; Ruschel, et al., 2017). This study confirms that production is associated with maintenance. In accordance with the present result, previous studies have demonstrated that it is necessary to have clear communications and interconnected information sharing through the MES (Lundgren, et al., 2020; Mantravadi, et al., 2020). This finding is consistent with that of Mantravadi, et al. (2020) who highlight the goal of using MES efficiently to speed up the access of the production data. It can be noticed that creating interconnected common database plays a critical role in solving the addressing issue of collecting the required data that is used in measuring and evaluating the performance. Another important finding was the benefits behind the integration of information systems. This result seems to be consistent with other research which found that the integration guarantee that data and information are complete (Polenghi, et al., 2021). Prior studies have noted the importance of system integration. According to Bokrantz, et al. (2020), integration has a relation to cross-functional collaboration between all entities. In addition, the integration of information systems establishes a common platform that ensures the correctness of the data. This result supports the idea of vertical system integration. According to Li, et al. (2019), integration of systems is categorized as vertical and horizontal integration. It is interesting to note that this study has shed light on the vertical integration, where production and maintenance departments agreed on the need to integrate different systems to manage and control various aspects of their common work. The goal of vertical integration is typically to improve profits by improving business operations (Wang, et al., 2016).

One interesting finding is the complexity of production systems. A possible explanation for this is that the dilemmas to have a free flow and transparency of reliable information, integrating and coordinating operational resources, and processes, and each process is linked into several systems are challenging in the production system. As mentioned in the literature review, the production system is a combination of important inputs that is used to produce the final output (Bruch & Rösiö, 2015). However, the role of an integrated information system in an organization can ensure that actions are aligned to the strategies and objectives to achieve the company's business goals (Metso, 2018). Another important finding was the importance of establishing a clear communication flow within the production units and maintenance to ensure the running of production. According to CEN (2011), the desired production output is achieved through a high level of availability, which is depending on the reliability of the equipment and maintainability, and maintenance supportability. Therefore, effective communication has become essential to making the right decisions, especially in business strategies. Besides, it facilitates the effectiveness to bring future changes in the organization.

Second, there is evidence that clear communication and information sharing between production and maintenance departments have a significant positive effect on the overall working way. The current study found that poor communication, no common databases, and lack of information sharing are hidden losses which in turn affect negatively on understanding the current situation and limits further continuous improvements. The most obvious finding to emerge from the analysis is that communication and information sharing can play an important role in addressing the issue of collecting the needed data. This study supports evidence from previous observations (e.g., Candell, et al., 2009; Ranasinghe, et al., 2011), who point out the lack of communication between people resulting in non-availability of relevant data and information. This finding was unexpected and suggests that it is necessary to establish a shared single big data which adds a new value to optimizing maintenance actions and production running (Metso, 2018). This finding is consistent with that of Sjödin, et al. (2018) who emphasize that the data collection procedure should be updated and shared among the relevant entities to achieve transparency.

The results of this study show that information is a significant resource. These results reflect those of Lopes, et al. (2016) who also found that information relates to effective coordination between all employees. As mentioned in the literature review, the information system that is used to maintain maintenance functions is called as CMMS (Lopes, et al., 2016). Prior studies that have noted the importance of CMMS in terms of planning, scheduling, managing, and monitoring maintenance operations related to machine, equipment, or other facilities and services (Tretten & Karim, 2014; Lopes, et al., 2016; Jamkhaneh, et al., 2018). At the present time, Maximo is used to handling these functions in the case company. According to Shankar, et al. (2021), CMMS has flexibility due to the company's uniqueness in terms of its own features in managing and monitoring maintenance operations. Likewise, Maximo is flexible to add features that are related to the data collection from the production environment.

Third, the study highlights the importance of measuring the key performance indicators especially in maintenance. Weber and Thomas (2005) state that “*It is not possible to manage what you cannot control, and you cannot control what you cannot measure*”. The findings of the literature review and the case study support the statement. In reviewing the literature, several authors highlight the potential usefulness of identifying the performance measures to identify the current situation and establish further improvements (Kennerley & Neely, 2003; Rouse & Putterill, 2003; Lundgren, et al., 2020). The result of this study indicates that the KPIs have a pivotal role in understanding and enhancing manufacturing system functioning. This finding was also reported by International Standard ISO 22400–1 (2014) and International Standard ISO 22400–2 (2014).

Neely and Bourne (2000) state that *“the trick is to measure as little as possible, but to ensure that you are measuring the things that matter”*. The intention of this study has been to evaluate the importance of a specific PI which is the availability and to compare the difference in calculating the machine availability between the maintenance and production departments due to not having an integrated common database. In reviewing the literature, several studies have noted the relationship between several PIs and how they are interrelated with each other (Ravelomanantsoa, et al., 2019; Lundgren, et al., 2020). In the literature on the maintenance of PIs, the difference is explained in terms of “leading” and “lagging” indicators. Leading indicators are used for activities carried out and lagging indicators for the effects of those activities (Muchiri, et al., 2011; Kumar, et al., 2013; Lundgren, et al., 2020). However, in the literature that has been studied and in the case of a company, all these indicators are called “performance indicators”. It has been agreed that both leading and lagging indicators should be measured to control actions according to their effects (Kumar et al., 2013). However, it is important to draw a distinction between what is done to impact performance and the performance itself.

The literature has emphasized MPM due to its benefits. MPM can be used as a robust methodology that allows companies to plan, monitor, and control their operation and business (Parida & Kumar, 2006). This can be accomplished by a deeper understanding of the operation and maintenance process, through the identification, development, and implementation of appropriate performance indicators (PIs) for the MPM system to achieve the company’s business goals (EN 15341:2019; Ravelomanantsoa, et al., 2019; Lundgren, et al., 2020)

Taken together, the findings of the literature review and the case study suggest that devising appropriate interrelated common databases to establish, maintain, and continuously develop communication and information sharing with the production and maintenance departments can bring crucial benefits for both sides of the industry. Not to mention, as long as the relationship is beneficial for both parties, they can increase their profits, interchange valuable knowledge, invest more in developing their businesses, and, consequently, remain competitive.

5.3. Analysis of RQ2

The second question in this study is *Which parameters or indicators can be taken into consideration to calculate machine availability among several production units in a manufacturing company?* Related with that, the purpose of this question was to review in detail the procedure of calculating machine availability among several production units in a manufacturing company. As suggested by Forza (2002) survey method was used to understand and learn managers’ attitude about this research question. According to low attendance of survey from production units, it was difficult to investigate all details related to availability calculations. Therefore, the survey was sent to 12 different production units’ managers, just 4 of them replied to the survey which makes the attendance ratio 33%.

SS-EN_13306 (2017) standard defines availability as *“Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided”* (2017). Related that definition, the question “How do you define availability?” was asked to attendees in survey. The answers were particularly similar like “Time when the machine is technically OK for production to use it.” and “high uptime, stable, easy to maintain” and “Uptime in the machine” and “Equipment ready and accessible for production”. These findings may be taken into

consideration as confirmation for is a general low knowledge about the availability in the case company.

The question about the importance of availability was asked to attendees to understand the perspective about this term was calculated as 4.5 out of 5 points means that attendees think calculation of machine availability is important as Bengtsson and Salonen (2017) mentioned, all factors need to strive for a successful outcome to obtain a high availability. Related that answers, next question was related to calculations of availability in different production units. Attendees answered as three of them calculates and one of them is belonged to one of the four production units which has not started to produce yet. As summary, it is critical to understand that there is a common mentality that availability is important in the production units.

As stated by Bengtsson and Salonen, (2007) there are different calculations for availability in literature and standards. So, the question “suggested formula of standardized machine availability calculation for all production units” was asked to figure out the knowledge in the case company through the survey. Four different answers were taken which are independent which showed that there is a misunderstanding or ambiguity about machine availability calculation as stated below:

1. $(\text{Planned production time} - \text{Technical losses}) / \text{Planned production time}$. Not to be mixed with OPE that is: $(\text{approved parts} \times \text{Cycle time}) / \text{Planned production time}$
2. Connected equipment, use data from source,
3. OPE
4. Just follow the industry standard

The question “Please explain the reason of suggesting this formula” in survey was answered as below by attendees which can be taken as generally it is suggested to use standard formulas:

1. It is defined from an overall perspective and should be used so we can compare the figures between different units. (SPS global office)
2. It's a common way of doing it
3. Info put in one time
4. One standard for all

The answers from attendees showed that the relationship between PI definitions is not separate but interrelated with each other as mentioned by Rodriguez, et al. (2009) and Kang, et al., (2016). Similarly, a clear understanding of this relationship can lead to more favorable outcomes and the establishment of actions based on the right decisions. Cost, productivity, time, flexibility, and quality are the five dimensions of performance. Effectiveness in a manufacturing industrial company and a production system can be defined as achieving the desired result, whereas efficiency refers to producing the product with the least amount of waste of time, money, and effort while maintaining a certain degree of customer satisfaction (De Toni & Tonchia, 2001). Since availability calculation is one of the most crucial PI for maintenance operations, these answers show that there is a need to define the machine availability for all production units.

5.4. Availability Calculations

In this section, the analysis of the availability calculations for different departments are measured, and concluded the outcomes.

5.4.1. Availability Calculations for DT

The data which was given by DT's maintenance engineers was used to calculate the real availability of machines and compare to SIM's calculations. The data was given through Maximo which are used in daily operations. Especially, immediate corrective maintenance (ICM) work orders were selected to see unplanned stoppages like breakdowns. DTOGP (Gearbox) and DTOAM (Rear Axle) products were selected. Related to the status of work orders, just completed and closed work orders were taken into consideration to supply reliability. When these filters were applied, total 116 work orders were selected between 2021 – October and 2022 – March duration. This duration was agreed to lower the numbers of work orders. The registered breakdowns were filtered and taken into consideration which were less than one day to show the calculation.

Total planned production time was calculated as total according to Table 8 as the days of workings and found as 1648 hours for selected work orders. If SIM calculates these 116 work orders, they would have assumed it as 2784 hours (24 hours work 116 work orders, 24 x 116). For the given work orders, total down time hours which was 132 hours can be seen in Table 16. As stated by Bengtsson and Salonen (2007), the formula below was used to calculate machine availability:

$$\frac{\text{Planned production time} - \text{stop time}}{\text{Planned production time}}$$

The calculation was done as below:

Table 16: Availability calculations for DT

Total Work Order Number	Total Down Time(hour)	Planned Production Time(hour)	Assumed Planned Production Time by SIM (hour)
116	132	1648	2784
	Real Availability	92%	
	Assumed Availability	95%	

5.4.2. Availability Calculations for DX

The data which was given by DX's maintenance engineers was used to calculate the real availability of machines and compare to SIM's calculations. The data was given through Maximo which are used in daily operations. Especially, immediate corrective maintenance (ICM) work orders were selected to see unplanned stoppages like breakdowns similarly DT. DX SV15383 / Shot Peening with 4 shifts and AVD4649 Carbon Sync with 3 shifts were selected. Related to the status of work orders, just completed and closed work orders were taken into consideration to supply reliability likewise DT calculations. When these filters were applied, total 240 work orders were selected between 2021 – October and 2022 – March duration. This duration was agreed to lower the numbers of work orders. The registered breakdowns were filtered and taken into consideration which were less than one day to show the calculation.

Total planned production time was calculated as total according to Table 9 for the days of workings and found 676 hours for Carbon Sync given 29 work orders, and 4677 hours for Shotpeening regarding given 211 work orders. Total down time information was taken from the Excel sheets which DX maintenance engineer selected and shared. This data was collected through Maximo from maintenance technicians with the help of work orders and these work orders were specifically selected by maintenance engineer to secure reliability. Planned production time calculations were done through accustomed shift planning for Carbon Sync and Shotpeening respectively. Assumed planned production time by SIM has been calculated like DT as 696 (29x24) hours for Carbon Sync and 5064 (211x24) hours for Shotpeening can be seen in Table 17.

As stated by Bengtsson and Salonen (2007), the formula below was used to calculate machine availability likewise calculations at DT:

$$\frac{\text{Planned production time} - \text{stop time}}{\text{Planned production time}}$$

Table 17: Availability calculations for DX

Name of production line	Shift	Total Work Order Number	Total Down Time (hour)	Planned Production Time (hour)	Assumed Planned Production Time (SIM) (hour)
Carbon Sync	3 shifts	29	119	676	696
Shotpeening	4 shifts	211	318	4677	5064
			Real Availability	Carbon - 3 shift	82%
			Assumed Availability		83%
			Real Availability	Shotpeening - 4 shift	93%
			Assumed Availability		94%

In Table 18, for total 240 (submission for Carbon Sync and Shotpeening) work orders, the difference between real and assumed availability is 0%. As Table 18 shows, there is no significant difference between real and assumed availability between the two calculation perspectives. This result may be explained by the fact that the provided sample size was limited. In addition, the provided planned production time from DX is missing the details of planned stoppages (like meetings, breaks, lunch, etc.).

Table 18: Total number of work orders calculations for DX

Total Work Order Number	Total Down Time (hour)	Planned Production Time (hour)	Assumed Planned Production Time (SIM) (hour)
240	437	5353	5760
		92%	92%
		Real Availability	Assumed Availability

5.4.3. General summary of calculations in DT and DX

With the formula of Bengtsson and Salonen (2007) suggested, the total 356 work orders were selected as case for this study. When the calculation was done, it was noticeable that there is a

difference between assumed machine availability and real machine availability percentage as 1% which can be followed in Table 19.

Table 19: Total selected work orders and calculation difference for this study

Production Unit	Total Work Orders	Total Down Time (hour)	Total Planned Production Time (hour)	Total Assumed Production Time(hour)
DT	116	132	1648	2784
DX	240	437	5353	5760
Total	356	569	7001	8544
		Assumed Availability	93%	
		Real Availability	92%	

As mentioned by Metso (2018), manufacturing companies' ability and motivation to establish a single platform are hampered by the usage of various systems. It is obvious that in the future, when DT and DX start to enter their daily production data like shift planning to Ebba in daily operation, and accordingly when there is an integration between Ebba and Data Lake, SIM will easily have the number of planned production time instead of assuming that each production units work 24 hours and 7 days. Even there is a small change for calculation today, it should be concluded that when there is a direct connection to this data through Data Lake, these calculations should be repeated to see the difference for all work order types regardless of filters which were used in this study. From the data in Table 19, it is apparent that there is a difference between the total planned production time (production perspective) and total assumed production time (maintenance perspective).

6. CONCLUSIONS AND RECOMMENDATIONS

The undertaken of literature review and a case study have attempted to highlight the potential usefulness of a fully integrated database among production and maintenance environments in measuring performance indicators. In addition to reviewing in detail the procedure of calculating machine availability among several production units in a manufacturing company.

This study has shown that the system integration will generate a stream of value-added in terms of creating better coordination between production and maintenance departments by maintaining equipment available to manufacturing which is aimed at capturing and sustaining a competitive advantage. The study has also shown the difference between maintenance and production perspective in calculating machine availability by 1% for the study sample which were selected from two production units. It is crucial to mention that the work orders were selected by maintenance engineers as the most reliable ones. The results provide a more accurate and reliable number for machine availability in the production environment. Although the current study is based on a small sample of production units as well as selected work orders. The small sample size did not allow in-depth analysis as well as the low attendance of the survey. The results of this investigation show that there is a difference in calculating the machine availability between production and maintenance due to the (1) no common database; (2) lack of communication; (3) no information sharing. Consequently, having an integrated common database will allow employees to access the same database at the same time when needed.

Overall, this study strengthens the idea that forming a collaborative common database between production and maintenance has a positive vital effect on understanding and enhancing manufacturing system functioning. In addition, communication and information sharing play a pivotal role in the success of future continuous improvements. The findings reported here provide inside on the process of communication among several production units, which is necessary to be taken into consideration for future development projects to achieve the desired goals.

This study provides implications for both academia and practitioners. The main theoretical implication of this study is that it has shed a contemporary light on the most effective relationship between production and maintenance. Moreover, it comprehensively examined and synthesized the success behind this relationship and how the relationship may be managed to harness the benefits of the collaboration in the industry to enhance the manufacturing system's functioning. An important practical implication of this study is that managers must pay particular attention to the process of communication in each production unit to achieve the desired performance outcomes. A second broad recommendation is that production and maintenance managers need to focus on communicating effectively and maintaining a high-quality association with each other to provide a solid foundation for future improvements. Thereby, it is possible to have a competitive advantage for the company.

It is clear that the manufacturing industry is undergoing paradigm shifts, and many manufacturing companies worldwide are currently updating their maintenance strategies aligned with smart maintenance. With the aim of securing productive, robust, and sustainable production systems through the implementation of the smart maintenance concept. Therefore, it can be suggested that before implementing smart maintenance technologies, starting to create a collaboration within common database in association with production units about production data sharing matter is crucial step for the case company.

The difference between Scania and SIM companies were described as a significantly impressive issue. Even SIM is a supplier of maintenance services for Scania AB in Sweden, it was a limitation for this study when SIM and Scania AB are different companies to find a correct person who provides the correct information related with study field. Accordingly, it was observed during field visits and meetings that employees think to integrate various systems which are used for different production units to a common database cannot be possible in terms of company differences. Although it was reported by IT department that these integrations are technically possible, it is recognized that managerial decisions for utilizing a common database to increase productivity can be a solution to determine these reflections from employees.

In terms of directions for future research, further work could also be conducted to explore the calculation difference in all other production units. Further, it would be interesting to repeat the calculations described here after covering all production units with all their work orders. A future study investigating several performance indicators would be very interesting to determine the relationship between them. In addition, a further study could assess the long-term effects of this integration and communication more closely between production and maintenance and explore its benefits.

7. REFERENCES

- Aboelmaged, M.G.S., 2015. E-maintenance research: a multifaceted perspective. *Journal of Manufacturing Technology Management*, 26 (5), pp.606-631.
- Alves, F., Badikyan, H., Moreira, H.A., Azevedo, J., Moreira, P.M., Romero, L. & Leitão, P., 2020. Deployment of a smart and predictive maintenance system in an industrial case study. *IEEE 29th International Symposium on Industrial Electronics (ISIE)*, pp.493-498.
- Al-Najjar, B., 2002. Data coverage and quality, diagnosis and maintenance decision, and their economic impact on the company's profits: case studies. Proceedings of the Conference of 16th International Euro maintenance 3–5 June, Helsinki, Finland, pp.283–293.
- Algabroun, H., Al-Najjar, B. & Ingwald, A., 2017. Assessment of the impact of maintenance integration within a plant using MFD: A case study. In the 12th World Congress on Engineering Asset Management. Brisbane, Australia.
- Alqahtani, A.Y., Gupta, S.M. & Nakashima, K., 2019. Warranty and maintenance analysis of sensor embedded products using internet of things in Industry 4.0. *International Journal of Production Economics*, 208, pp.483-499.
- Arab, A., Ismail, N. & Lee, L.S., 2013. Maintenance scheduling incorporating dynamics of production system and real-time information from workstations. *Journal of Intelligent Manufacturing*, 24(4), pp.695-705.
- Bamber, C.J., Castka, P., Sharp, J.M. & Motara, Y.M., 2003. Cross-functional team working for overall equipment effectiveness (OEE). *Journal of Quality in Maintenance Engineering*, 9, pp.223-238.
- Bellgran, M. & Säfsten, K., 2010. *Production development design and operation of production systems*. [Online]. London: Springer.
- Bengtsson, M. & Salonen, A., 2007. Dependability-Calculations in: Reliability, Maintainability, Maintenance Supportability, Availability, and Overall Equipment Effectiveness, Mälardalen Högskola, Report No. IDPIoDTR: 07: 02.
- Bengtsson, M. & Salonen, A., 2016. Requirements and Needs-A Foundation for Reducing Maintenance-Related Waste. *10th World Congress on Engineering Asset Management (WCEAM)*, pp. 105-112.
- Bokrantz, J., Skoogh, A., Berlin, C. & Stahre, J. 2017. Maintenance in Digitalised Manufacturing: Delphi-Based Scenarios for 2030. *International Journal of Production Economics*, 191, pp.154-169.
- Bokrantz, J., Skoogh, A., Berlin, C., Wuest, T. & Stahre, J., 2020. Smart Maintenance: a research agenda for industrial maintenance management. *International Journal of Production Economics*, 224, pp.107547.
- Bruch, J. & Rösiö, C., 2015. *Support for successful Production System Development: Handbook*.
- Brundage, M.P., Morris, K.C., Sexton, T., Moccozet, S. & Hoffman, M., 2018. Developing Maintenance Key Performance Indicators from Maintenance Work Order Data. *Manufacturing Equipment and Systems*, 3.
- Bumblauskas, D., Gemmill, D., Igou, A. & Anzengruber, J., 2017. Smart Maintenance Decision Support Systems (SMDSS) based on corporate big data analytics. *Expert Systems with Applications*, 90, pp.303-317.
- Cachada, A., Barbosa, J., Leitão, P., Gcraldcs, C.A., Deusdado, L., Costa, J., Teixeira, C., Teixeira, J., Moreira, A.H., Miguel, P. & Romero, L., 2018. Maintenance 4.0: Intelligent and Predictive Maintenance System Architecture. *2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA)*, 1, pp.139-146.

- Candell O., Karim R. & Söderholm P., 2009. eMaintenance – Information logistics for maintenance support, *Robotics and Computer-Integrated Manufacturing*, 25 (6), pp.937-944.
- Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M. & Yin, B., 2018. Smart factory of industry 4.0: key technologies, application case, and challenges. *IEEE Access*, 6, pp.6505-6519.
- Chong, S., Pan, G., Chin, J., Show, P.L., Yang, T. & Huang, C., 2018. Integration of 3D Printing and Industry 4.0 into Engineering Teaching. *Sustainability* 2018, 10 (11), pp.3960.
- De Toni, A. & Tonchia, S., 2001. Performance measurement systems-models, characteristics, and measures. *International Journal of Operations and Production Management*, 21 (1-2), pp.46-71.
- Denscombe, M., 2014. The good research guide: for small scale research projects (2nd ed.). Maidenhead: Open University Press.
- Dinardo, G., Fabbiano, L. & Vacca, G., 2018. A smart and intuitive machine condition monitoring in the Industry 4.0 scenario. *Measurement: Journal of the International Measurement Confederation*, 126, pp.1-12.
- Erboz, G., 2017. How To Define Industry 4.0: Main Pillars of Industry 4.0. *Managerial trends in the development of enterprises in globalization era*, pp.761-767.
- Fagerström, B., 2004. Managing distributed product development: An information and knowledge perspective.
- Forza, C., 2002. Survey research in operations management: a process-based perspective. *International Journal of Operations & Production Management*, 22 (2), pp.152-194.
- Franciosi, C., Voisin, A., Miranda, S., Riemma, S. & Iung, B., 2020. Measuring maintenance impacts on sustainability of manufacturing industries: from a systematic literature review to a framework proposal. *Journal of Cleaner Production*, 260, pp.121065.
- Frishammar, J. & Hörte, S.Å., 2005. Managing External Information in Manufacturing Firms: The Impact on Innovation Performance. *Journal of Product Innovation Management*, 22 (3), pp.251–266.
- Frost, T., Nöcker, J., Demetz, J. & Schmidt, M., 2019. The evolution of Maintenance 4.0–What should companies be focusing on now. In the Proceedings of 4th International Conference on Maintenance Engineering, Dubai UAE, pp. 123-132.
- Galar, D., Gustafson, A., Tormos, B. & Berges, L., 2012. Maintenance Decision Making based on different types of data fusion. *Eksploatacja i Niezawodność - Maintenance and Reliability*, 14 (2), pp.135.
- Gallo, T. & Santolamazza, A., 2021. Industry 4.0 and human factor: How is technology changing the role of the maintenance operator? *Procedia Computer Science*, 180, pp.388-393.
- Giliyana, S., Salonen, A. & Bengtsson, M., 2022. Perspectives on Smart Maintenance Technologies - A Case Study in Large Manufacturing Companies, *Advances in Transdisciplinary Engineering series*, 21, pp. 255-266.
- Gopalakrishnan, M., Subramaniam, M. & Skoogh, A., 2022. Data-driven machine criticality assessment–maintenance decision support for increased productivity. *Production Planning & Control*, 33 (1), pp.1-19.
- Guillén López, A.J., Crespo Márquez, A., Macchi, M. & Gómez Fernández, J.F., 2018. Prognostics and health management in advanced maintenance systems. In book: Crespo Márquez, A., González-Prida Díaz, V., Gómez Fernández, J.F., *Advanced Maintenance Modelling for Asset Management*. 1st ed. Cham: Springer International Publishing, pp.79-106.
- Hassan, Q.F., 2011. Demystifying cloud computing. *CrossTalk* 24, pp.16-2
- Herterich, M.M., Uebernickel, F. & Brenner, W., 2015. The Impact of Cyber

- Physical Systems on Industrial Services in Manufacturing. *Procedia CIRP*, 30, pp.323-328.
- International Standard ISO 22400–1. 2014. *Automation Systems and Integration – Key Performance Indicators (KPIs) for Manufacturing Operations Management - Part 1: Overview, Concepts and Terminology*. Geneva: International Standard Organization (ISO).
- International Standard ISO 22400–2. 2014. *Automation Systems and Integration – Key Performance Indicators (KPIs) for Manufacturing Operations Management - Part 2: Definitions and Descriptions*. Geneva: International Standard Organization (ISO).
- International Organization for Standardization (IEC), 2016. IEC 62264-3:2016 *Enterprise control system integration – Part 3: Activity models of manufacturing operations management*.
- Jamkhaneh, H.B., Pool, J.K., Khaksar, S.M.S., Arabzad, S.M. & Kazemi, R.V., 2018. Impacts of computerized maintenance management system and relevant supportive organizational factors on total productive maintenance. *Benchmarking: An International Journal*, 25 (7), pp.2230-2247.
- Kang, N., Zhao, C., Li, J. & Horst, J.A., 2016. A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems. *International Journal of Production Research*, 54 (21), pp.6333-6350.
- Karkalos, N.E., Markopoulos, A.P. & Davim, J.P., 2019. General Aspects of the Application of Computational Methods in Industry 4.0. In: *Computational Methods for Application in Industry 4.0*. Springer Briefs in Applied Sciences and Technology. Springer, Cham.
- Kennerley, M. & Neely, A., 2003. Measuring performance in a changing business environment. *International Journal of Operations & Production Management*, 23 (2), pp.213-229.
- Kumar, U., Galar, D., Parida, A., Stenström, C. & Berges, L., 2013. Maintenance performance metrics: a state-of-the-art review. *Journal of Quality in Maintenance Engineering*, 19 (3), pp.233-277.
- Labib, A.W., 1998. World-class maintenance using a computerized maintenance management system. *Journal of Quality in Maintenance Engineering*, 4 (1), pp.66-75.
- Laudon, K.C., & Laudon, P., J, 2000. *Management information systems*. 13th ed. Prentice Hall: Upper Saddle River.
- Lee, J., Kao, H.A. & Yang, S., 2014. Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment. *Procedia CIRP*, 16, pp.3-8.
- Lee, J., Bagheri, B. & Kao, H., 2015. A Cyber-Physical Systems architecture for Industry 4.0 based manufacturing systems. *Manufacturing letters*, 3, pp.18-23.
- Li, D., Fast-Berglund, Å. & Paulin, D., 2019. Current and future Industry 4.0 capabilities for information and knowledge sharing: Case of two Swedish SMEs. *The International Journal of Advanced Manufacturing Technology*, 105 (9), pp.3951-3963.
- Lindberg, C.F., Tan, S., Yan, J. & Starfelt, F., 2015. Key performance indicators improve industrial performance. *Energy procedia*, 75, pp.1785-1790.
- Liu, X., Wang, W. & Peng, R., 2015. An integrated production and delay-time based preventive maintenance planning model for a multi-product production system. *Eksploatacja i Niezawodność*, 7 (2), pp.215-221.
- Liu, X., Peng, R., Li, Q. & Ma, X., 2017. Joint optimization of preventive maintenance and economic production quantity with considering demand adjustment. In: *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, IEEE. p.1916-1919.
- Ljungberg, Ö., 1998. Measurement of overall equipment effectiveness as a basis for TPM activities. *International Journal of Operations & Production Management*, 18, pp.495-507.

- Lopes, I., Senra, P., Vilarinho, S., Sá, V., Teixeira, C., Lopes, J., Alves, A., Oliveira, J.A. & Figueiredo, M., 2016. Requirements specification of a computerized maintenance management system—a case study. *Procedia Cirp*, 52, pp.268-273.
- Lundgren, C., Bokrantz, J. & Skoogh, A., 2020. Performance indicators for measuring the effects of Smart Maintenance. *International Journal of Productivity & Performance Management*, 70 (6), pp.1291-1316.
- Misztal, A., Butlewski, M., Belu, N., & Ionescu, L. M., 2014. Creating involvement of production workers by reliable technical maintenance. In: International Conference on Production Research-Regional Conference Africa, Europe and the Middle East (ICPR-AEM)/3rd International Conference on Quality and Innovation in Engineering and Management (QIEM), pp.322-327.
- Mantravadi, S., Jansson, A.D. & Møller, C., 2020. User-Friendly MES Interfaces: Recommendations for an AI-Based Chatbot Assistance in Industry 4.0 Shop Floors. *ACIIDS*.
- Markeset, T., Kumar, U., 2001. R&M and Risk-Analysis Tools in Product Design, to Reduce Life-Cycle Cost and Improve Attractiveness, PROCEEDINGS Annual RELIABILITY and MAINTAINABILITY Symposium.
- Marilungo, E., Papetti, A., Germani, M. & Peruzzini, M., 2017. From PSS to CPS Design: A Real Industrial Use Case Toward Industry 4.0. *Procedia CIRP*, 64, pp.357–362.
- Metso, L. & Kans, M., 2017. An Ecosystem Perspective on Asset Management Information. *Management Systems in Production Engineering*, 25 (3), pp.150-157.
- Metso, L., 2018. Information-based industrial maintenance—an ecosystem perspective. PhD Thesis, Lappeenranta University of Technology, Lappeenranta.
- Metso, L., Baglee, D. & Marttonen-Arola, S., 2018. Maintenance as a combination of intelligent IT systems and strategies: a literature review. *Management and Production Engineering Review*, 9 (1), pp.51-64.
- Moenaert, R.K. & Souder, W.E., 1990. An information transfer model for integrating marketing and R&D personnel in new product development projects. *Journal of Product Innovation Management*, 7 (2), pp.91-107.
- Mostafa, S., Lee, S. H., Dumrak, J., Chileshe, N. & Soltan, H., 2015. Lean thinking for a maintenance process. *Production & Manufacturing Research*, 3 (1), pp.236-272.
- Muchiri, P., Pintelon, L., Gelders, L. & Martin, H., 2011. Development of maintenance function performance measurement framework and indicators. *International Journal of Production Economics*, 131 (1), pp.295-302.
- Neely, A., Gregory, M. & Platts, K., 1995. Performance measurement system design: a literature review and research agenda. *International Journal of Operations and Production Management*, 15 (4), pp.80-116.
- Neely, A. & Bourne, M., 2000. Why measurement initiatives fail. *Measuring Business Excellence*, 4, pp.3-6.
- Neely, A., Mills, J., Platts, K., Richards, H., Gregory, M., Bourne, M. & Kennerley, M., 2000. Performance measurement system design: developing and testing a process-based approach. *International Journal of Operations and Production Management*, 20 (10), pp.1119-1145.
- Neely, A., Gregory, M. & Platts, K., 2005. Performance Measurement System Design: A Literature Review and Research Agenda. *International Journal of Operations & Production Management*, 25 (12), pp.1228–1263.
- Olaf, J.M. & Hanser, E., 2018. Manufacturing in Times of Digital Business and Industry 4.0 - The Industrial Internet of Things Not Only Changes the World of Manufacturing, in *Advances in Manufacturing Engineering and Materials*. Cham: Springer International Publishing. pp. 11–17.

- Ooijevaar, T., Pichler, K., Di, Y. & Hesch, C., 2019. A Comparison of Vibration based Bearing Fault Diagnostic Methods. *International Journal of Prognostics and Health Management*, 10 (008).
- Parida, A. & Kumar, U., 2006. Maintenance performance measurement (MPM): issues and challenges. *Journal of Quality in Maintenance Engineering*, 12 (3), pp.239-251.
- Parida, A. & Chattopadhyay, G., 2007. Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM). *Journal of Quality in Maintenance Engineering*, 13 (3), pp.241-258.
- Parida, A., Kumar, U., Galar, D. & Stenström, C., 2015. Performance measurement and management for maintenance: a literature review. *Journal of Quality in Maintenance Engineering*, 21 (1), pp.2-33.
- Peres, R.S., Rocha, A.D., Leitao, P. & Barata, J., 2018. IDARTS – Towards intelligent data analysis and real-time supervision for industry 4.0. *Computers in Industry*, 101, pp.138-146.
- Pintelon, L. & Van Puyvelde, F., 1997. Maintenance performance reporting systems: some experiences. *Journal of Quality in Maintenance Engineering*, 3 (1), pp.4-15.
- Pisano, G.P., 1997. *The Development Factory: Unlocking the Potential of Process Innovation*, Harvard Business Review Press, Boston, MA.
- Polenghi, A., Roda, I., Macchi, M. & Pozzetti, A., 2021. A methodology to boost data-driven decision-making process for a modern maintenance practice. *Production Planning & Control*, pp. 1-17.
- Qi, Q. & Tao, F., 2018. Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison. *IEEE Access*, 6, pp.3585-3593.
- Rahmati, S. H. A., Ahmadi, A. & Karimi, B., 2018. Multi-objective evolutionary simulation-based optimization mechanism for a novel stochastic reliability centered maintenance problem. *Swarm and Evolutionary Computation*, 40, pp.255-271.
- Ranasinghe, D.C., Harrison, M., Främling, K. & McFarlane, D., 2011. Enabling through life product-instance management: Solutions and challenges. *Journal of network and computer applications*, 34 (3), pp.1015-1031.
- Randolph, J., 2009. A guide to writing the dissertation literature review. *Practical Assessment, Research and Evaluation*, 14 (1), pp.1-13.
- Ravelomanantsoa, M.S., Ducq, Y. & Vallespir, B., 2019. A state of the art and comparison of approaches for performance measurement systems definition and design. *International Journal of Production Research*, 57 (15-16), pp.5026-5046.
- Raza, T., Muhammad, M.B. & Majid, M.A.A., 2016. A comprehensive framework and key performance indicators for maintenance performance measurement. *ARPN Journal of Engineering and Applied Sciences*, 11 (20), pp.12146-12152.
- Rishel, T. D. & Christy, D. P., 1996. Incorporating Maintenance Activities into Production Planning; Integration at the Master Schedule Versus Material Requirements Level. *International Journal of Production Research*, 34 (2), pp.421-446.
- Rodriguez, R.R., Saiz, J.J.A. & Bas, A.O., 2009. Quantitative relationships between key performance indicators for supporting decision-making processes. *Computers in Industry*, 60 (2), pp.104-113.
- Roy, R., Stark, R., Tracht, K., Takata, S. & Mori, M., 2016. Continuous maintenance and the future – Foundations and technological challenges. *CIRP Annals*, 65 (2), pp.667-688.
- Rouse, P. & Putterill, L., 2003. An integral framework for performance measurement. *Management Decision*, 41 (8), pp.791-805.
- Ruschel, E., Santos, E.A.P. & Loures, E.D.F.R., 2017. Industrial Maintenance Decision Making: A Systematic Literature Review. *Journal Of Manufacturing Systems*, 45, pp.180-194.
- Salloum, M., 2013. Explaining the evolution of performance measures – a dual case-study approach. *Journal of Engineering Project and Production Management*, (3), p.99.

- Santolamazza, A., Cesarotti, V. & Introna, V., 2018. Anomaly detection in energy consumption for Condition-Based maintenance of Compressed Air Generation systems: an approach based on artificial neural networks. *IFAC-PapersOnLine*, 51 (11), pp.1131-1136.
- Schreiber, M., Vernickel, K., Richter, C. & Reinhart, G., 2019. Integrated production and maintenance planning in cyber-physical production systems. *Procedia CIRP*, 79, pp.534–539.
- Shankar, L., Singh, C.D. & Singh, R., 2021. Impact of implementation of CMMS for enhancing the performance of manufacturing industries. *International Journal of System Assurance Engineering and Management*, pp.1-22.
- Silvestri, L., Forcina, A., Introna, V., Santolamazza, A. & Cesarotti, V., 2020. Maintenance transformation through Industry 4.0 technologies: A systematic literature review. *Computers in industry*, 123, pp.103335.
- Simoes, J.M., Gomes, C.F. & Yasin, M.M., 2011. A literature review of maintenance performance measurement: a conceptual framework and directions for future research. *Journal of Quality in Maintenance Engineering*, 17 (2), pp.116-137.
- Simoes, J., Gomes, C.F., & Yasin, M.M., 2016. Changing role of maintenance in business organisations : measurement versus strategic orientation. *International Journal of Production Research*, 54, pp.3329-3346.
- Smith, R. & Mobley, R.K., 2011. Rules of Thumb for Maintenance and Reliability Engineers, Butterworth-Heinemann, Oxford, UK.
- Sjödin, D.R., Parida, V., Leksell, M. & Petrovic, A., 2018. Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing Moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, processes, and technologies. *Research technology management*, 61 (5), pp.22-31.
- Swink, M., Narasimhan, R. & Wang, C., 2007. Managing beyond the factory walls: Effects of four types of strategic integration on manufacturing plant performance. *Journal of Operations Management*, 25 (1), pp.148-164.
- Säfsten, K. & Gustavsson, M., 2020. *Research methodology: for engineers and other problem solvers*. Studentlitteratur AB.
- Tangen, S., 2005. Analysing the requirements of performance measurement systems. *Measuring Business Excellence*, 9, pp.46-54.
- Tao, F., Qi, Q., Liu, A. & Kusiak, A., 2018. Data-driven smart manufacturing. *Journal of Manufacturing Systems*, 48, pp.157-169.
- Tao, F. & Qi, Q., 2019. New IT Driven Service-Oriented Smart Manufacturing: Framework and Characteristics. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 49 (1), pp.81-91.
- The European Committee for Standardization (CEN), 2001. *EN 13306: Maintenance Terminology*, Brussels.
- The European Committee for Standardization (CEN), 2017. *EN 13306: Maintenance Terminology*, Brussels.
- The European Committee for Standardization (CEN), 2019. *EN 15341: Maintenance Key Performance Indicators*, Brussels.
- Tretten, P. & Karim, R., 2014. Enhancing the usability of maintenance data management systems. *Journal of Quality in Maintenance Engineering*, 20 (3), pp.290-303.
- Turkulainen, V., 2008. Managing cross-functional interdependencies – the contingent value of integration. PhD thesis, Helsinki University of Technology, Helsinki.
- Wang, S., Wan, J., Li, D. & Zhang, C., 2016. Implementing Smart Factory of Industrie 4.0: An Outlook. *International Journal of Distributed Sensor Networks*, 12.

- Weber, A. & Thomas, R., 2005. Key performance indicators: measuring and managing the maintenance function. Ivara Corporation.
- Webster, J. & Watson, R.T., 2002. Analysing the past to prepare for the future: writing a literature review. *MIS quarterly*, 26 (2), pp.xiii-xxiii.
- Wienker, M., Henderson, K. & Volkerts, J., 2016. The computerized maintenance management system an essential tool for world class maintenance. *Procedia Engineering*, 138, pp.413-420.
- Wong, C.S., Chan, F.T.S. & Chung, S.H., 2013. A Joint Production Scheduling Approach considering Multiple Resources and Preventive Maintenance Tasks. *International Journal of Production Research*, 51 (3), pp.883–896.
- Xiang, F., Yin, Q., Wang, Z. & Jiang, G.Z., 2018. Systematic method for big manufacturing data integration and sharing. *The International Journal of Advanced Manufacturing Technology*, 94 (9), pp.3345-3358.
- Yan, J., Meng, Y., Lu, L. & Li, L., 2017. Industrial Big Data in an Industry 4.0 Environment: Challenges, Schemes, and Applications for Predictive Maintenance. *IEEE Access*, 5, pp.23484- 23491.
- Yin, R. K., 2018. Case Study Research and Applications: Design and Methods, 6th ed. Thousand Oaks, CA: Sage publications, Los Angeles.
- Ylipää, T., Skoogh, A., Bokrantz, J. & Gopalakrishnan, M., 2017. Identification of maintenance improvement potential using OEE assessment. *International Journal of Productivity and Performance Management*, 66 (1), pp.126-143.
- Zheng, P., Lin, T.J., Chen, C.H. & Xu, X., 2018. A systematic design approach for service innovation of smart product-service systems. *Journal of cleaner production*, 201, pp.657-667.
- Zolotová, I., Papcun, P., Kajáti, E., Miskuf, M. & Mocnej, J., 2018. Smart and cognitive solutions for Operator 4.0: laboratory H-CPPS case studies. *Computers & Industrial Engineering*, 139, pp.105471.

APPENDICES

APPENDIX 1 – Survey Questions

1. Production Unit Full Name and Abbreviation
2. Contact Person (Name and Surname)
3. Contact Person – Title
4. How do you define machine availability? (With couple of sentences)
5. Calculation of machine availability is... (Please select 1 to 5 according to importance)
6. In your production unit, do you calculate machine availability?
7. If there is not a calculation of machine availability, please explain the reason of not calculating with a few words.
8. If there is a calculation of machine availability, who is the responsible person of this calculation? (If you are not the responsible, please write the name of contact person)
9. If there is a calculation of machine availability, which system do you use to get the required data?
10. If there is a calculation of machine availability, how do you calculate? (Formula is the best answer for that question. But experience sharing, previous documentation etc. are also acceptable answers. If you don't calculate, please write "No calculation".)
11. If there is a calculation of machine availability, please select your type of calculation.
12. If there is a calculation of machine availability, do you think it is the correct way of calculation?
13. If there is a calculation of machine availability, do you make some assumptions while calculating? (If you don't calculate, please write "No calculation". If you calculate and have assumptions, please explain what kind of assumptions you do, otherwise please write "no assumptions")
14. If there is a calculation of machine availability, do you face any problems?
15. If you face any problems with calculation, please specify these problems
16. Do you think that machine availability is a necessary KPI for production units? (Please select 1 to 5 according to importance)
17. What is your suggested formula of standardized machine availability calculation for all production units?
18. Please explain the reason of suggesting this formula.

APPENDIX 2 – Fixed questions which asked during each interview

1. Do you know if Ebba has planned production time data (like they plan stoppages or something) and is it possible to have this data into Data Lake?
2. Is it possible to integrate “planned production time” data in all systems into the Data Lake? If yes? How long time will take to implement that solution?
3. What are the current integrations between Ebba systems and others and which systems are integrated into the Data Lake?