CHALMERS
UNIVERSITY OF TECHNOLOGY

Investigation into the Benefits of Using a Predictive Maintenance System

A study of KUKA Nordic´s customers experiences

Master's thesis in Production Engineering

Ellinor Jansson

DEPARTMENT OF INDUSTRIAL AND MATERIAL SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2025
www.chalmers.se

Master's thesis 2025

Investigation into the Benefits of Using a Predictive Maintenance System

A study of KUKA Nordic´s customers experiences

Ellinor Jansson

Department of Industrial and Materials Science
Chalmers University of Technology
Gothenburg, Sweden 2025

Investigation into the Benefits of Using a Predictive Maintenance System
A study of KUKA Nordic´s customers experiences
Ellinor Jansson

Supervisors: Elin Hybert, KUKA Nordics, Daniel Nilsson, KUKA Nordics and Zeynab Allahkarami, Department of Industrial and Materials Science
Examiner: Anders Skoogh, Department of Industrial and Materials Science

Master's Thesis 2025
Department of Industrial and Materials Science
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: KUKA industrial robotic arm and a laptop displaying the iiQoT platforms interface.

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2025

Investigation into the Benefits of Using a Predictive Maintenance System
A study of KUKA Nordic´s customers experiences
Ellinor Jansson
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

This thesis investigates the benefits of using a predictive maintenance system (PdM), focusing on KUKA Nordic's customers. The study includes a systematic literature review, which discovered the key components of a PdM architecture, together with benefits such as environmental and financial improvements, and challenges including cybersecurity and knowledge-gap within the maintenance departments.
The thesis also includes a qualitative study including a questionnaire and interviews with KUKA Nordic's customers. It identified key barriers to implement PdM, such as data management and no use for the collected data. The qualitative study also discovered the importance of KUKA robots in customers´ production and evaluated the current conditions for using KUKA´s PdM tool in their iiQoT platform.

The thesis main findings includes the discovery that mature equipment as industrial robots might not benefit as much from using PdM and emphasizing the need for more information and education about it. Suggesting further research to explore the benefits of PdM on different types of equipment and different company sizes. It highlighted the importance of addressing data management and -security concerns, overcoming implementation resistance, and considering sustainability impacts in maintenance strategies.

Keywords: Predictive maintenance, Industry 4.0, systematic literature study, interviews, questionary.

Acknowledgements

This report presents the outcome of a master thesis conducted at KUKA Nordics, carried out at Chalmers University of Technology at the department of Industrial and material science.

I want to thank supervisors Elin Hybert and Daniel Nilsson at KUKA Nordics for their support and guidance. Their combined efforts, along with everyone at KUKA Nordics, have ensured a welcoming environment from the very beginning.
Additionally, I would like to thank my supervisor, Zeynab Allahkarami, and my examiner, Anders Skoogh, for their supervision and valuable insights throughout the project.

Ellinor Jansson, Gothenburg, May, 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

CBM	Condition based maintenance
CRM-system	Consumer relation management system
Ind4.0	Industry 4.0 or The 4th industrial revolution
IoT	Internet of things
MQTT	Message Queuing Telemetry Transport. Communication protocol for efficient communication between IoT devices
PdM	Predictive maintenance
RQ	Research questions
SLS	Systematic Literature Study

Contents

List of Figures

List of Tables

1
Introduction

1.1 Background

Predictive maintenance (PdM) is a maintenance strategy that consists of physical properties being monitored to predict failures [1]. It requires the production facilities to have sensors to monitor the physical properties and transfer data to an analytics tool. The sensor data is used to predict future events, allowing maintenance to be scheduled at the most suitable time [2].
Problems can occur when managing the collected data [2] and to collect all data needed to get adequate predictions. Insufficient data from previous breakdowns can hinder the ability to predict when and why a failure might occur [3].
Predictive maintenance is a maintenance strategy that will be relevant as more companies transition towards Industry 4.0(Ind4.0). Introducing a new way to optimize and manage production assets, which can minimize maintenance stoppages [4].

KUKA Nordics sells and distributes industrial robots, applications and software to its customers around Scandinavia and the Baltic region. They provide a platform(iiQoT) that can be connected with Internet of Things (IoT) sensors already integrated in KUKA industrial robots. It continuously collects data from the connected robots and allows to see actions made on the robots, failures, together with other data such as running time and total cycles. The platform has multiple features, which include a predictive maintenance tool.
The customer base shows an interest in the platform, but lacks intention to implement it in the near future. The few customers who have access to iiQoT are far from using it to its full capacity. The current barriers for companies to fully implement PdM are unknown. A deeper investigation of the topic is therefore needed to see if the problem has any connection to iiQoT itself or if it is related to something else.

**KUKA Nordics will be referred to as KUKA in the rest of this thesis*

1.2 Aim

The project aims to investigate how companies can benefit from using predictive maintenance on their KUKA robots in production. The following research questions will be used as support:

RQ1: What frameworks are needed for a successful predictive maintenance system?

RQ2: What are the effects of implementing predictive maintenance?
RQ3: What barriers can prevent customers from implementing predictive maintenance using the KUKA´s iiQoT platform?

1.3 Scope

The aim of the project is to investigate how KUKA‘s customers can benefit from using a PdM system. Exploring the reason for the lack of interest in using iiQoT and looking into the possible requirements for it to be more attractive.
The intention is also to discover what is required for a successful implementation and how it would impact the customers´ production. To understand if some industries benefit more from implementing the system compared to others.

The project will not include a full implementation of a predictive maintenance system. It will not cover the technology that iiQoT is based on, as the aim of this project is to discover what is required for customers to start using it. Making the specific machine learning method not relevant for this study.
The project will also be limited to the information given by KUKA and their customers, on which this project heavily relies. A limited number of interviews will be conducted with representatives from KUKA´s customers. This will impact the conclusions that can be drawn from it, as a limited sample group might not be representative to all industries.

1.4 Case study company- KUKA Nordics

KUKA sells and distributes industrial robots, software and services in the Nordic and Baltic region. They have identified four trends, common for most manufacturing industries and across their customers. Which are guiding them in their development of new products.
- change in demographic
- mass customisation
- resource efficiency
- fast availability

The trends align with the drivers of Ind4.0 and indicates a demand on connected automation that can easily be adjusted. These impact the requirements on KUKA´s industrial robots, but also on the platforms and software that they provide.

1.4.1 iiQoT

They have offered for over a years a maintenance analytics system(iiQoT), a platform to monitor individual- or fleets of robots. The platform continuously collects data, which can be used to implement both condition-based maintenance or PdM on existing industrial robots. iiQoT collects up to 40,000 different sensor values, which can be analysed through KUKA´s own interface and applications. The other option is for the customer to use the raw data to develop their own interface. The PdM system in iiQoT predicts and alerts the user of potential failures on the robots.

The iiQoT platform is divided into two versions, Basic and Advanced. iiQoT.Advanced contains the same applications as iiQoT.Basic, but also offers additional tools such as the PdM-application which will be the focus of this thesis.

1.4.1.1 iiQoT framework

The current framework to connect a KUKA industrial robot to iiQoT is shown in figure 1.1. The robots are connected to a common tenant that enables the data collected from the robots to be transferred over internet to a cloud based server. The data can then be collected from the cloud and visualised in the iiQoT interface. KUKA provide the industrial robots that are prepared to be connected and the iiQoT platform. The integration of the system is on the other hand done by the customers themselves.

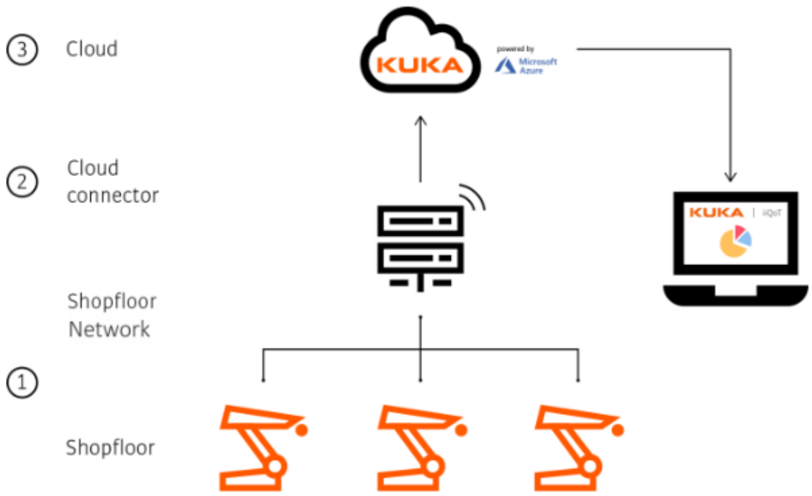


Figure 1.1: KUKA´s current framework

The integration of iiQoT and the industrial robots are the same independent on if iiQoT.Basic or iiQoT.Advanced is used. The user can easily switch between the two versions without changing anything with the hardware or industrial robots.

2

Theory

2.1 Industry 4.0

Industry 4.0 is a concept that represent the new era of integrating automation and digitalisation in manufacturing industries [5]. The term comes from the forth industrial revolution, as the technologies included revolutionizes the methods used in manufacturing sectors. The focus is to implement digital tools and automated solution, with the intent of connecting the physical and virtual environment to get productivity and sustainability benefits [5].

Financial and environmental gains with Industry 4.0 comes through better resource efficiency, productivity improvements and optimising equipment usage [6]. The concept is supposed to meet the demand of mass customisation, while using human and physical resources efficiently. The aim is to replace humans with automated assets were physical strain is common and instead use humans for more complex tasks [7]. Challenges surround integrating the infrastructure needed to handle the data required for the digitalised tools within Ind4.0.
Cyber security also acts as a barrier as the risk of attacks on critical systems appear more frequently when cloud based storage is used [6].

2.2 Maintenance strategies

A decided way to complete maintenance tasks, which include restoring equipment to keep a production running [8]. Maintenance strategies is divided in proactive and reactive maintenance, were the first mentioned is an action carried out before a fault occurs, while the latter is done when the equipment is already broken [8]. Figure 2.1 shows all subcategories of proactive- and reactive maintenance.

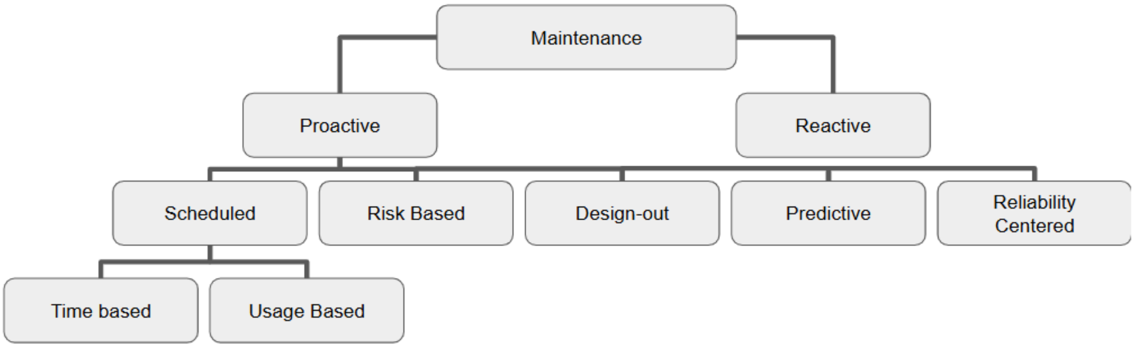


Figure 2.1: Types of maintenance strategies, based on [8]

2.2.1 Reactive maintenance

Reactive maintenance, sometimes called corrective maintenance is when no action is carried out to prevent failures on a equipment [9]. This is usually used on less expensive equipment that are easy to change, as it address issues when they appear.

2.2.2 Proactive maintenance

Proactive maintenance, also called preventive maintenance is a maintenance strategy that carries out actions before failures can occur[8]. It including monitoring and scheduling of different actions such as inspections, repairs and services. Proactive maintenance contains multiple different types of maintenance strategies, with the common trait that they are a preventative action carried out before a failure happens.
Proactive maintenance is preferred if the consequence of the equipment failing is exceeding the cost of repairing it before a failure can happen [9].

2.2.2.1 Predictive maintenance

Predictive maintenance is a maintenance strategy that uses data collected regularly from equipment to predict future failures [1]. The philosophy is to base maintenance actions of data, enabling repairs being made when its needed and not just on a time interval. Leading to less unnecessary stoppages and failures [1]. Taking the performance of the equipment into account allows for a more flexible maintenance strategy were data driven decision making plays a role instead of more conventional corrective- or scheduled maintenance [11].

The cost of maintenance can also be reduced using PdM as it can optimise when and how often tasks are carried out. Allowing to schedule repairs when it least affect the production while still avoiding a full break down [1]. Figure 2.2 shows when PdM reacts to a failure compared to other maintenance strategies. The ability to react just before a failure happen allows for cost reduction in the maintenance action and reduced stoppages in the running production. While never allowing the equipment to fail, which can lead to more critical damage that can take longer to repair.

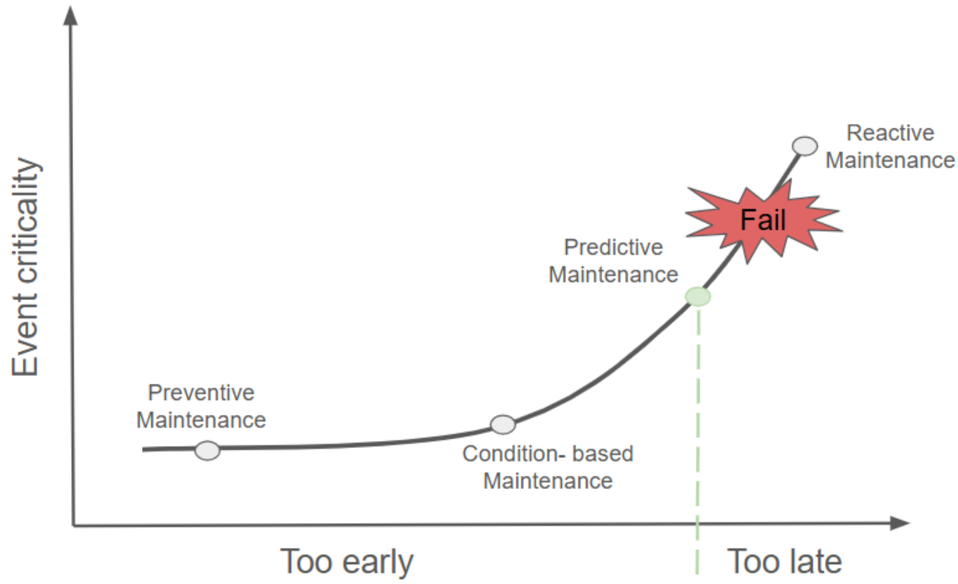


Figure 2.2: Event criticality, comparing different maintenance strategies, based on [13]

PdM is dependant on the accessibility of IoT and a stable network infrastructure. The required data need to be collected with small intervals to ensure reliability of the prediction [5]. The data also needs to be stored, which puts a high demand on data security and - storage. Opening up new challenges not experienced before.

2.3 Prior Predictive maintenance applications

Predictive maintenance can be used using multiple different approaches, which are divided into three different groups[31]:
- Data-driven
- Knowledge based
- Physical model-based

This thesis covers Predictive maintenance using the data-driven approach, which is the only one that can be applied in a Ind4.0 setting. It uses as described in 2.2.2.1 *Predictive Maintenance* IoT sensors and other technology to perform the predictions. This is a method developed to accommodate for demands part of the implementation of Ind4.0.
Knowledge-based and physical model-based predictive maintenance relies on previous knowledge about the equipment. It requires employees with plenty of skill within the field and can be hard to remain consistent with change among the workforce.

3
Methods

3.1 Thesis methodology

The thesis consisted of two types of studies; a systematic literature study and a qualitative study consisting of sit-down interviews and a questionnaire. The project was set up like this to get a full view of the aim and to be able to answer the research questions(RQs) in a sufficient way. The project started with the literature study and transferred to the qualitative study around halfway through the projects timeline. Figure 3.1 shows how the RQs was answered and the actions performed to achieve it.

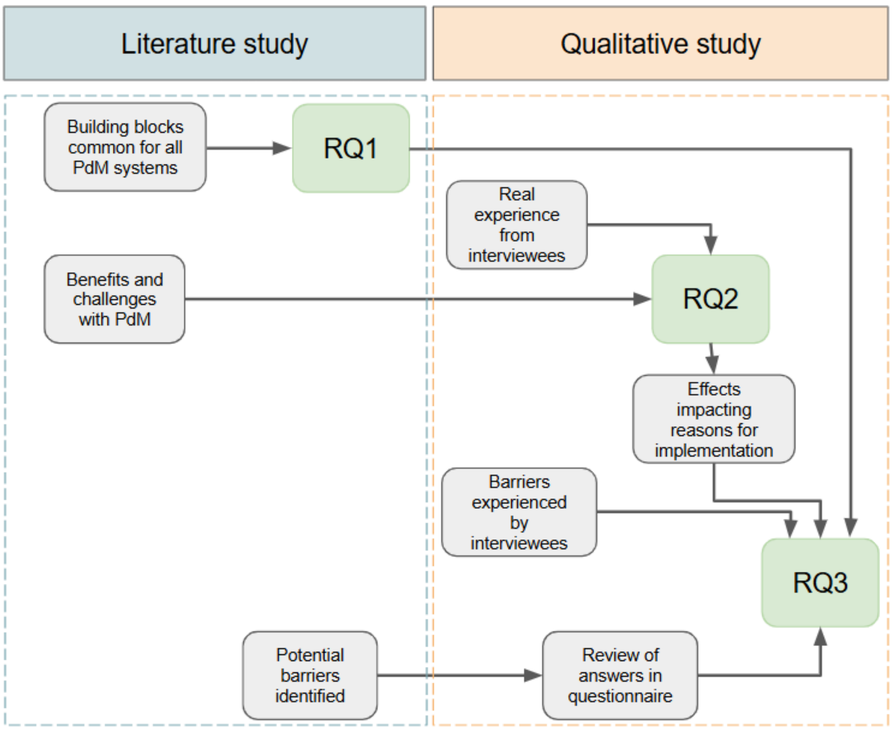


Figure 3.1: Visual representation of the thesis methodology

The research questions were answered in chronological order, to allow the result from the previous one to answer the next. This gave the opportunity to explore the benefits with PdM through the collected knowledge of both studies. RQ1 was answered using the literature study, RQ2 and 3 was discovered through both studies.

As seen in figure 3.1, subjects discovered earlier in the project could be used to answer a RQs later on.

3.2 Systematic literature review

The systematic literature study(SLS) was conducted using an established method to ensure that the selected articles remained relevant to the projects aim. A systematic study was used to maintain clarity and avoid errors or biases from the author [12], which could be a issue if not a clear methodology was used. The study therefore followed some pre-determined stages that can be divided in to three overarching steps: Define scope, Evaluate papers, Analyse and Present takeaways.

Each of the three steps contain different stages, which are detailed activities to perform a successfully systematic study. The first stage include defining the aim and the scope the study will be achieved within. This is done by setting clear exclusion criteria and define the initial search terms, which is crucial to achieve a successful study as the other stages is dependent on it. A vaguely defined aim or unclear exclusion criteria can make the study difficult or not narrow enough to have a real value.

The evaluation step consists of the search for papers in the selected database. This is achieved through several steps of assessments to get relevant papers that covers the aim of the study, while not complying with the exclusion criteria.

The final stages included identifying key topics and takeaways from the selected papers. To identify a research gap and present a comprehensive review about the selected subject. Figure 3.2 shows all stages and in which order they were completed.

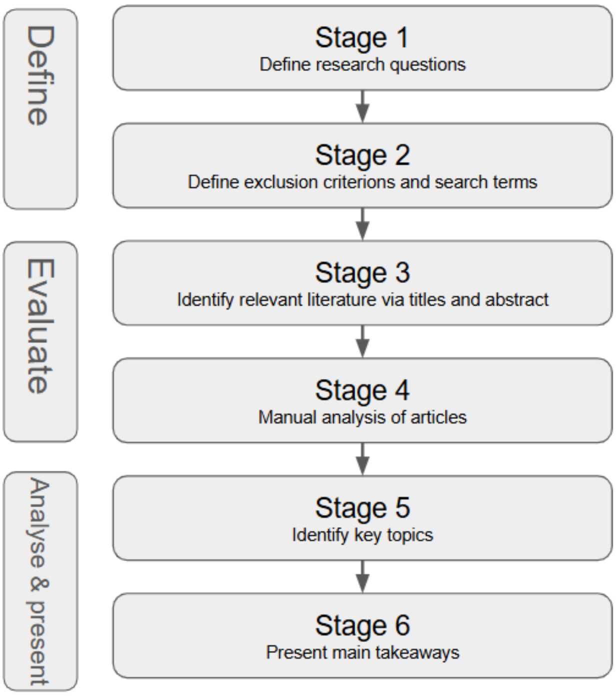


Figure 3.2: Stages of systematic literature study, based on [19], [42] and [43]

3.3 Qualitative study

The qualitative study contained a set of interviews and a questionnaire. This was mainly to get a good understanding of the costumers perspective on PdM using iiQoT. The two methods complemented each other by giving more detailed answers for each question through the interviews. While the questionnaire gave data about a wider range of companies, allowing to investigate discovered trends. Figure 3.3 shows how topics and key takeaways were generated.

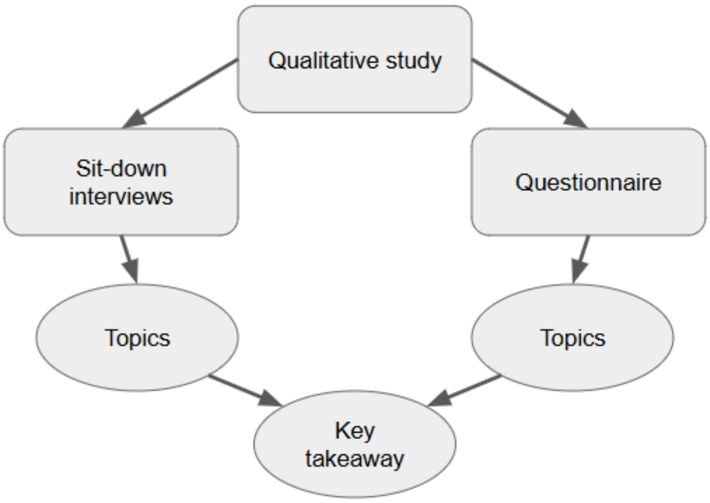


Figure 3.3: Topics generation from the qualitative study

The sample selection was the same for both interviews and questionnaire, only difference being that the interviews were conducted with a smaller sample size. As the topic was narrow with the interviewees being highly specialised within maintenance on automated production. The data was handled in different ways as the questionnaire generated some quantitative data and not just qualitative one as the interviews. The key takeaways from the qualitative study were then compared with the systematic literature study to generate topics and trends relevant for the project.

3.3.1 Interviews

The interviews contained a set of open-ended predetermined questions that the interviewee was able to talk around [14], together with follow up questions generated during the interviews. The interviews were meant to discover patterns related to the research questions and to cover the subject in more details, which made the semi-structured approach suitable [15]. The interviews was carried out with each interviewee individually and lasted for 15-20 minutes.
The questions generated was different for each interview as they were made with the answers from the questionnaire in mind. To get a more in-depth view of how that specific customer resonated around PdM, as all had different approaches. It allowed the interviewee to elaborate around each question and gave a deeper discussion. Therefore, providing more information on the topic than what could be prepared in advance[14].

3.3.1.1 Generating questions

The interview questions were generated based on the research questions together with answers from the questionnaire and topics from the literature study. The interviews were held after each participant had filled in the questionnaire and it was therefore used as a guide to ensure relevant questions for each interviewee. Some questions were common for all interviews while some were customised for every interview. This gave a better understanding on how that particular interviewee resonated around PdM. Giving more insight into the different approaches towards it. The questions asked in each interview is attached in appendix A.

The questions was limited to remain relevant to the topic and in general supported by established theory. This enabled the interviewee group to be limited, as all were specialised within the topic [15]. The number of questions was also kept to only a couple, to limit the time for each interview. This required that every asked question was well formulated and considered to ensure that the interview stayed relevant. Each question had to add additional information about how the interviewee resonated around the topics brought up in the questionnaire. They were open ended to ensure that a discussion followed, were the topic could be thoroughly analysed.

3.3.1.2 Interviewees- and sample selection

The four-point approach to qualitative sampling was used to define and decide the sample size [16]. The method developed by Robinson [16] takes the projects scope and timeline into account when deciding the sample size. It describes that qualitative studies usually contain smaller sample sizes [17], which enables each interviewee to have a primary role in the study [16]. How the method was used is described in table 3.1.

Name	Definition	Key decisional issues
Point 1	Define a sample universe Establish a sample universe, specifically by way of a set of inclusion and/or exclusion criteria	 Homogeneity vs. heterogeneity, inclusion and/or exclusion criteria
Point 2	Decide on a sample size Choose a sample size or sample size range, by taking into account what is ideal and what is practical.	 Ideographic (small) vs. nomothetic (large)
Point 3	Devise a sample strategy Select a purposive sampling strategy to specify categories of person to be included in the sample.	 Stratified, cell, quota, theoretical strategies
Point 4	Source the sample Recruit participants from the target population.	 Incentives vs. no incentives, snowball sampling varieties, advertising

Table 3.1: The four-point approach to qualitative sampling, based on [16]

<u>Point 1</u>
The sample universe was decided to be homogenous through the type of company and the role that the interviewee had, asking people with knowledge about PdM and automated production. While letting the heterogeneity be in the approach towards PdM, ensuring that different approaches was investigated.
This was done due to convenience, as KUKA´s customer base align with this arrangement. Contact information was already availably, making approaching the potential interviewees easier. The following criteria was also set up:
1. KUKA customer
2. Manufacturing company
3. Had KUKA industrial robots in the daily production

<u>Point 2</u>
As the topic was narrow together with a sample universe with much knowledge within the field, enabled to have a smaller sample size. Taking the timeline of the project into account made the range for interviews between 3 and 8 people[16]. With

the additional information collected through the questionnaire, allowed to keep the number of interviews to the lower side of the range.

Point 3
The sample strategy was to directly contact people that work within the maintenance department at companies with different approaches to PdM. It was a stratified sampling as every interviewee was selected for their part of a specific grouping of the population.

Point 4
Every interviewee was contacted directly through email and asked if they wanted to participate in the study. The contact information was already accessible through KUKA´s customer service. Follow-up email were sent to those that did not give a response within a week from the initial email.

3.3.1.3 Transcription of interviews and data analysis

All interviews were held through Microsoft teams and the transcription was done through the platforms built in function. Automatic transcription was used to remain accurate to what was said. The method also excluded the time to manually transcribe the interviews from a recorded voice track, which made the project more efficient while delivering accurate transcriptions.

The data generated from the interviews was analysed continuously during the interview period. The aim was to achieve saturation of the study, a concept in which no new themes emerge from the interviews. This was done by adding questions that arose between interviews and during analysis. When the study reaches saturation, no new themes or topics should be brought up in the interviews. This indicates that all major topics within the scope of the study have been covered [14]. The data was analysed using the thematic analysis, a six step approach shown in figure 3.4.

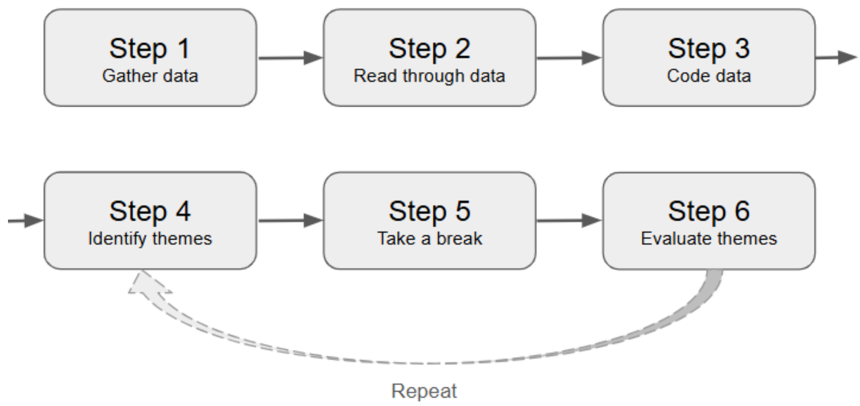


Figure 3.4: Thematic approach

Thematic analysis was used as it is a systematic approach and ensures that all data was handled equally [18]. The steps included to gather and read the transcriptions, ensuring that there was a good understanding of what was covered in each interview. The data was then analysed to identify different codes that emerged. These was then compared to other interviews, where similar codes was identified as an overarching theme. This process can take multiple times to complete as some themes might take longer to find, while others might not end up being as important as first thought. It was therefore important to take a break before evaluating the themes to ensure that no mistakes were made.

3.3.2 Questionnaire

The questionnaire consisted of 12 questions, presented to the responders using Microsoft form. The entire questionnaire is shown in appendix B. Its purpose was to gather quantitative data on a broader range of KUKA's customers' approaches to PdM. The quantitative data was used to complement the information collected through the interviews to find common topics. The questionnaire also acted as a base to generate questions for the interviews, ensuring that all questions were relevant and added value to the study.

3.3.2.1 Generating questions

The questionnaire was divided into three sections; "About you", "About your organisation" and "Predictive maintenance". The two first sections was to get a overview of the responder and their organisation. Most questions were designed to have respondents rank statements on a scale from 1 to 5, allowing for varying degrees of agreement and enabling the collection of more detailed data.
Some questions focused specifically on KUKA's iiQoT platform, while others addressed predictive maintenance (PdM) more generally. The goal was to understand each customer's approach to PdM and whether it differed from their use of the iiQoT PdM tool for their KUKA robots. This provided insights into why the platform was not being used, as well as potential reasons unrelated to KUKA.
The questionnaire allowed respondents to indicate whether any of the predetermined barriers were specifically applicable to their organization. This approach was chosen instead of having respondents identify barriers on their own. The number of interview participants was too limited to ensure overlapping responses, which would have made it difficult to draw meaningful conclusions. Therefore, a set of predetermined barriers was presented, all based on Industry 4.0 challenges related to digitalization [6]. These were considered relevant for this study, as predictive maintenance is a means of digitalizing production as part of Ind4.0.

3.3.2.2 Sample selection

The sample selection was the same as the one for the interviews. All steps can be seen in 3.3.1.2 *Interviewees- and sample selection.* The only difference being that the company´s approach to PdM was not taken into account when the question to participate in the study was sent out. This was done to allow a bigger sample group chosen with a random selection within the decided sample universe.

3.3.2.3 Data analysis

The collected data was compiled and presented automatically using Microsoft form. Trends and topics were discovered when comparing results from the different questions. The data was then compiled to reveal relevant trends that helped answering the research questions.

4 Systematic literature study

4.1 Research design

The systematic literature study(SLS) was conducted to collect and analyse the research already established within the field [20]. Using a clear plan to ensure a systematic approach was vital to avoid authors assumptions being transferred to the research. Instead, the aim was to identify relevant data and present it in a transparent way [20]. The study was limited to answer the research questions, keeping the literature study systematic by only reviewing relevant articles. The study followed predetermined steps to make the method repeatable.

The SLS was aimed to answer RQ1 and RQ2 in 1.2 *Aim*. Some information was gathered to ensure that RQ3 could be answered in the qualitative study. This information will be covered in 5.1 *Questionnaire answers* in the result chapter and will therefore not be presented further in the SLS. The search terms were produced based on the aim and research questions and exclusion criterion was created to help limit the study to only include accessible and relevant articles. The selected articles were reviewed using the criteria in multiple steps, and the most relevant articles were selected. Common topics and trends were identified and further researched if necessary. The process and identified topics were then presented.

4.1.1 Selecting search terms and exclusion criteria

The articles were sourced via the database Scopus, accessed through Chalmers Library. It was used as it contains peer-reviewed scientific papers with well functioning search and filter functions. The database contain a verity of articles, books and conference papers allowing for a wide range of sources. All articles could be accessed in full text, allowing access to all potential sources.
The search terms used were based on the research questions. The aim was to use broad search terms and limit the number of articles through the different review steps shown in figure 4.1 using the exclusion criteria. A wide range of papers within each area allowed for a better chance to discover relevant articles. The search terms used to identify articles relevant for RQ1 and can be seen in table 4.1, those related to RQ2 are shown in 4.2.

Search terms
"Predictive maintenance" AND "Implement" AND "Effects"
"Predictive maintenance" AND "Achieve" AND "Effects"
"Predictive maintenance" AND "Benefits"
"Predictive maintenance" AND "Improvements"
"Predictive maintenance" AND "Challenges"
"Predictive maintenance" AND "Environment*" OR "Sustainability*"

Table 4.1: Used search terms for RQ1

Search terms
"Predictive maintenance" AND "Framework"
"Predictive maintenance" AND "System"
"Predictive maintenance" AND "Architecture"

Table 4.2: Used search terms for RQ2

The exclusion criteria were generated to ensure a unbiased study that could review every article equally during the evaluation stages. They were intended to assist in removing articles not relevant or that could not be used. The following creations were made:
1. not written in English
2. not accessible through Chalmers Library
3. the search terms not included in the abstract, keywords or title
4. published before 2015
5. not connected to aim or research questions

The criteria were carefully selected to not affect the study´s outcome, instead exclude articles that for different reasons were not relevant to the study or would impact the ease of evaluation. The articles had to remain relevant and accessible as full text, which limited the article selection. There was also a requirement that the articles had to be readable and the language was therefore limited to English.

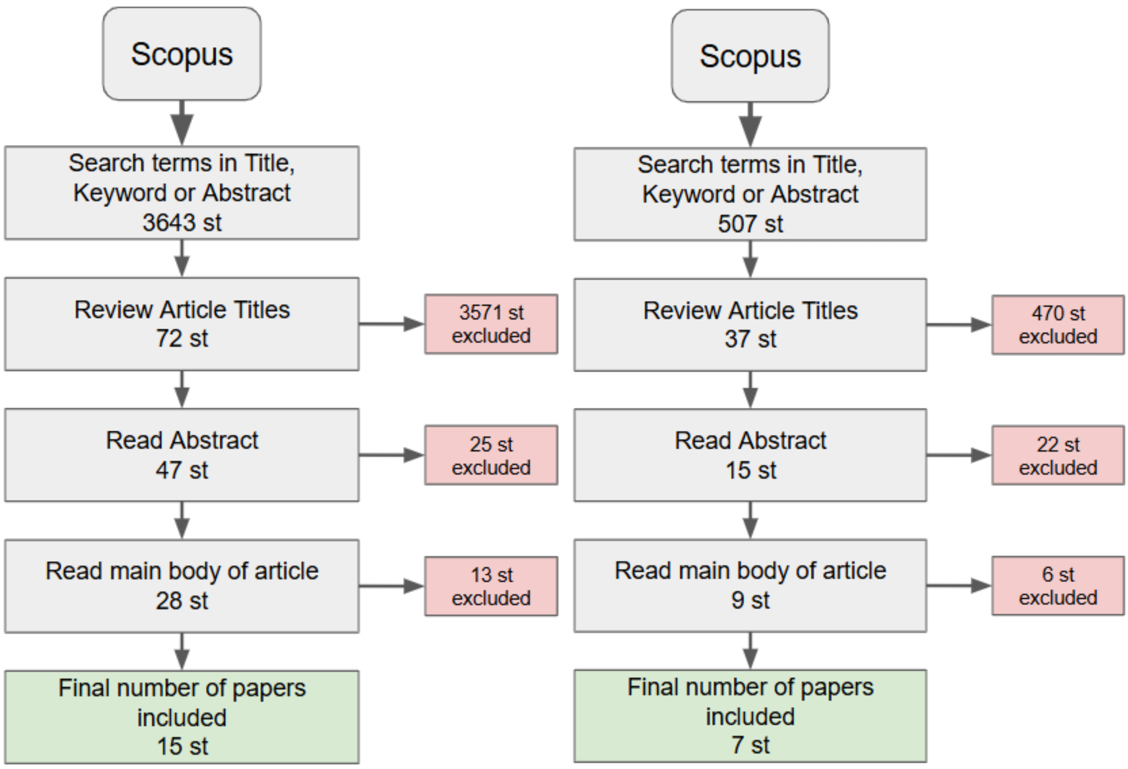
The limit on publication date was applied to avoid any outdated information, as the field of PdM is constantly evolving in a fast pace. Between 5-10 years back in time as publication time-span can be used as a rule of thumb to ensure no outdated publications was included in the study[15]. Also, given that Industry 4.0 was introduced in 2013 [6], a 10-year time span was considered relevant, as articles discussing predictive maintenance from an Ind4.0 perspective began appearing around 2015. This time-span helped ensure that the publications included in the study were grounded in Ind4.0 principles. Therefore, made it possible to compare the findings from the SLS with those from the qualitative study, which focused on the iiQoT platform—developed using Ind4.0 technologies.

The criterion that the search terms had to be included in the keywords, abstract or title was mainly used in the first exclusion steps. Whereas the last criteria that the

article had to be connected to the research question or aim were used during the manual analysis of the articles.
Limiting the articles with the exclusion criterion ensured a more streamlined evaluation stage, where only relevant papers were further reviewed. Ensuring a systematic and relevant literature study.

4.1.2 Evaluation

The evaluation was done by qualitatively reviewing the selected papers in different steps to continuously remove irrelevant articles. The exclusion criteria were used to ensure that the study remained consistent throughout the process. The evaluation began by applying the search terms in the Scopus database. Multiple search terms were used to gather information for the two research questions, and the relevant search terms for each question were combined and shown in figure 4.1. Each selected article´s title was reviewed and those not relevant were excluded. The abstract of the remaining articles was then reviewed and the ones that met the exclusion criteria were removed. The final stage was to read the main body of the articles to get an overarching understanding of the content. The decision on which articles to include in the final study was made based on their relevance and quality. Figure 4.1 shows the steps in the evaluation stage and the number of articles that were reviewed and excluded in each step. Appendix C includes the final batch of articles used in the systematic literature study.



(a) RQ1 **(b)** RQ2

Figure 4.1: Evaluation process

4.1.3 Analysis and presentation

Each selected article were analysed, then related topics and trends were identified. The purpose was to get an overarching understanding of the available research within the area. Reoccurring topics connected to the projects aim and the research questions, together with the identified research gap were then presented. Showing a wide overview of each topic, which gave a deeper understanding on how it affected the impression of PdM. Giving more insight into PdM and how it might affect the production sector.
Both benefits and challenges were presented to show a unbiased representation of the field and the complexity involved in an integration. This was compared with the data collected through the qualitative interviews and questionnaire. Allowing for further insight and topic identifications that would not have been possible without the systematic literature study.

4.2 Descriptive analysis

The descriptive analysis was done to quantitively evaluate the selected articles for the systematic literature study. The aim was to evaluate the distribution of the collected data, using different methods to evaluate the parameters of the findings. It gave a overview of the data allowing to describe the basic characteristics of the study.
All data is based on the combination of the articles collected to answer RQ1 and RQ2. No distinctions was made between the two groups of articles, as the topic was so closely related to only impact the result marginally.

4.2.1 Time evolution

Figure 4.2 shows the year of publication across all articles collected in the SLS. The time-span used during the search was between 2015 and 2025, but selected articles started in 2017. The number of articles was even until 2022, when an increase could be seen. The drop in 2025 is due to the study being carried out in march, making that data not comparable to the rest which include full years of publications.

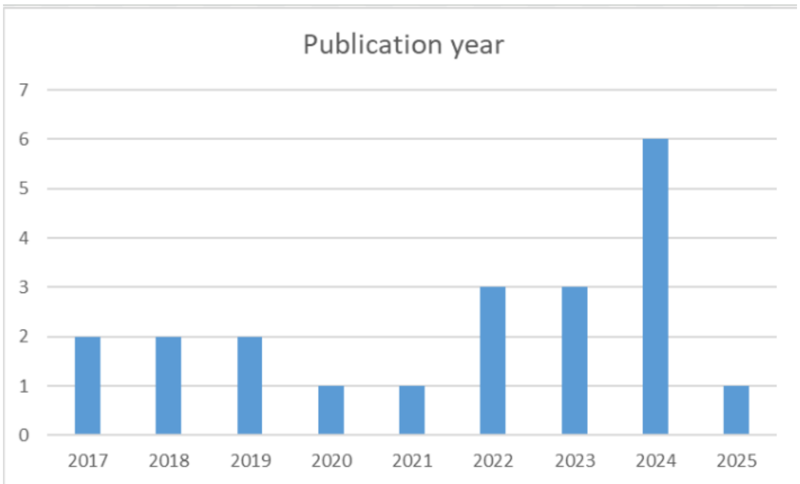


Figure 4.2: Publication year of papers included in the systematic literature study

4.2.2 Geographic distribution

Figure 4.3 shows the geographic distribution of the included articles around the world. The number of publications from each country is evenly distributed. Most articles are published in the European region. While Asia, Africa , north- and south America are represented with one or a few articles each. The results shows that PdM is researched across the entire world, but mostly covered in Europe.

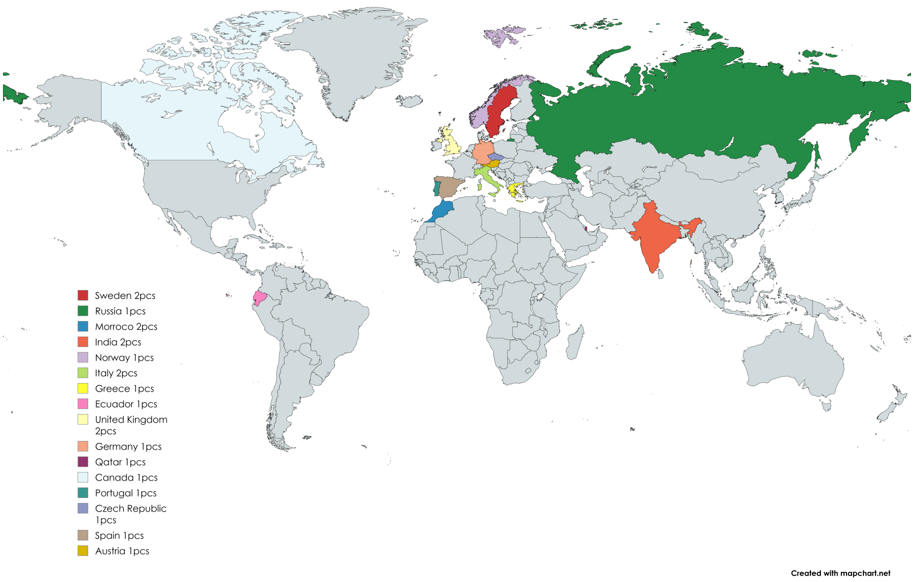


Figure 4.3: Demographic distribution of papers included in the systematic literature study

4.2.3 Type of publication

Type of publication are distributed between reviews, conference papers and articles. Reviews and conference papers was similar in distribution, while most was articles as shown in figure 4.4. No books or book chapters were included in the study.

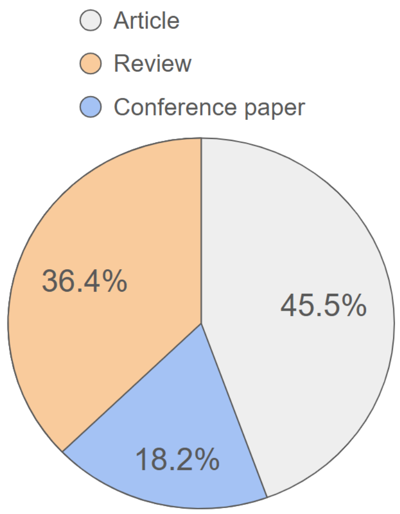


Figure 4.4: Type of publication included in the systematic literature study

4.3 Content analysis

The content analysis consists of the key topics identified in the evaluation step of the SLS. Each topic consist of specific areas that were reoccurring in the included articles. Each section covers the current research within the area, based on the articles included in the study. The analysis presents the main takeaways and the discovered research gap, which will be used to compare to topics identified in the qualitative study.

4.3.1 Predictive maintenance framework architecture

The PdM framework have a quite similar high-level layout even when the separate building blocks can be done in different ways. The system requires a set of data sources, which all the other steps emerges from. The sources can be IoT sensors, historical data or manual inputs [34] from maintenance staff [29]. To be classified as a Ind4.0 technology the input needs to be data-driven, excluding data based on staffs previous knowledge [31].

The data transfer is done via a industrial standard messaging protocol for IoT such as MQTT or similar [32], transferring the information to an edge gateway which performs the data analysis. This step can be done in multiple ways using different algorithms or machine learning tools to make the most accurate predictions [29]. Research is done on the different methods to determine how accurate the predictions can be [34].

The predictions is then transferred via internet to a cloud based system that visualises and stores the data for the user [32]. This system can be connected to the

company´s other digital infrastructure such as CRM- or other maintenance systems [29]. How integrated this connection is depends on how the specific PdM system is developed. Together they act as a base for scheduling maintenance actions.
The cloud based system is also connected both ways with an interface, the technician can use it to report the result of a maintenance task and view the reports from the predictions [32]. A representation of the framework is shown in figure 4.5. The exact layout can vary between different creators, but it overall follows the same structure.

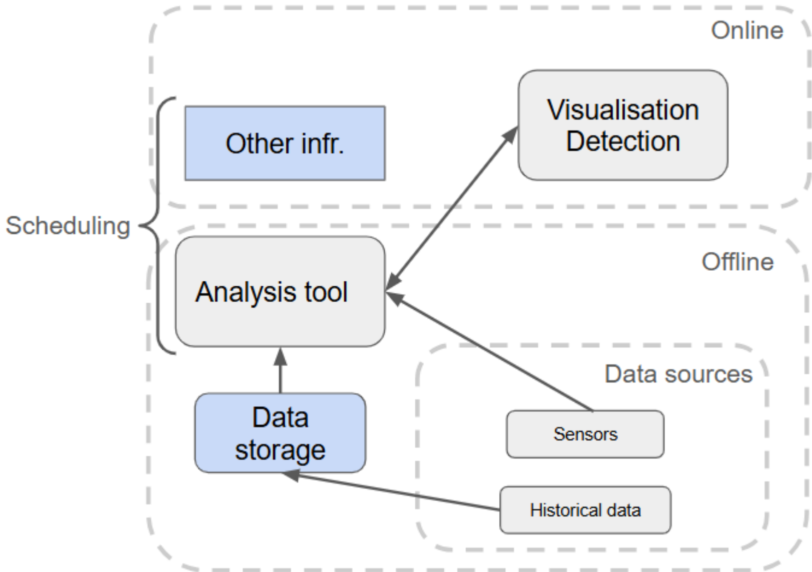


Figure 4.5: System architecture for PdM, based on [29, 32, 33, 34, 35, 36]

The process of how a predictive maintenance action is completed can be seen in figure 4.6. Starting by data being collected and processed to create representative features and parameters. These are the base for the analysis to get a status of the equipments health, to predict if any failures can happen in the near future [33]. The system then creates and recommends a maintenance action. Showing it via an interface to the maintenance worker [32]. All steps are visualized in chronological order through the building block in figure 4.5.

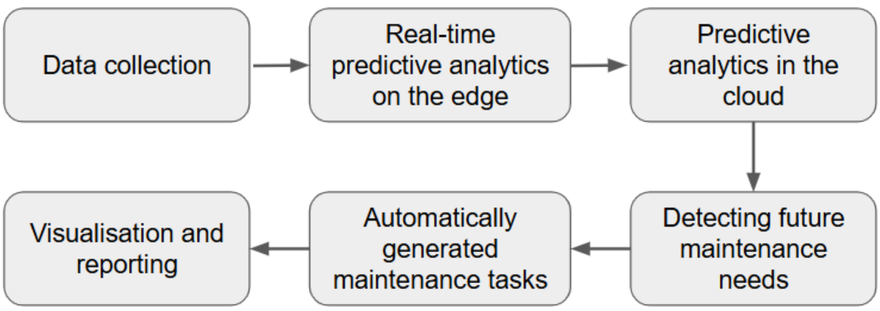


Figure 4.6: PdM process, based on [32]

4.3.2 Benefits with Predictive maintenance

Predictive maintenance is a maintenance strategy that enables to foresee failures, allowing to take action before the equipment fails. PdM uses historical data about an equipment to predict the probability of failure. It can also propose maintenance actions, avoiding potential fatal equipment failures and dangerous situations [28]. PdM can limit the time the equipment are being maintained and the number of maintenance operations needed [24]. The strategy has multiple benefits connected to production planning, utilization, maintenance costs, reduced downtime, together with other aspects [21]. PdM acts as a platform to conduct multiple of the technologies developed for Ind4.0. IoT, digitalised production systems and big data analytics connects well with a PdM system to fulfil the intentions with Ind4.0 [21]. It also allows for a faster failure analysis and have the ability to mitigate the root cause of failures [23]. Enabling a more efficient maintenance system, while minimizing time for trouble shooting and the risk for recurring failures.

4.3.2.1 Environmental advantages

Manufacturing industries can reduce their environmental impact with the help of PdM. Increased production efficiency can improve the utilization of resources [37]. This can be done by optimising maintenance schedules and reducing unplanned stoppages, together with increasing equipments lifespan by preventing possible fatal failures before they can occur. Avoiding the need to replace equipment, can save both valuable time and resources [41]. This can also limit the required energy consumption, directly reducing the plant´s environmental footprint.
PdM can reduce the amount of material going to waste [41] and assist in optimising spare parts storage. This can both reduce the space needed for material storage and the extent of waste management.

4.3.2.2 Financial and productivity improvement

With the implementation of big data management and continuous monitoring of equipment- productivity improvements can be made by optimizing the equipments performance. Which allows for a more efficient and cost effective production [27]. PdM can also improve the reliability [23] by preventing failures, avoiding wasted work hours and material.
Unplanned production stops can be minimized, leading to an more efficient scheduling and recourse distribution [27]. PdM can save about 8-12 percent in maintenance cost related to preventive actions being scheduled unnecessary [37]. Especially when time for repairs and services of equipment can be predicted and planned to occur during a suitable time [27], as during a already planned production stop or when no production is scheduled to take place. Making the utilization of resources higher, by avoiding storing unnecessary amounts of spare-parts or having maintenance staff without any work [28]. PdM also assist in continuos improvement by presenting data that maintenance workers can draw conclusion from. Leading to an increase in productivity and improved budget allocation, which is enabled when reliable forecast can be done [27].

4.3.3 Challenges with implementing Predictive maintenance

Even though PdM is recognised as a maintenance strategy for the future of production, challenges surrounding implementation and management remain unsolved.
It adds complexity to the production system that was not present before its implementation. This is mainly due to the added sensors and the required internet connectivity needed to collect and transfer data to the PdM platform [21]. These are aspects that have not been needed before and can be challenging to implement in a running production. Additionally, training maintenance staff adds to the complexity of the implementation [37].

The combination of costly sensors, software and infrastructural changes needed to implement PdM makes it challenging for small- and medium sized companies(SME) to benefit from the strategy [26]. The initial investment with added cost of data storage and -analysis for running the maintenance activities can be demanding on a company with a limited budget and a smaller allocation for investments [26]. Fully implementing PdM, whether for only critical equipment or all machinery, is a costly process that requires significant investment [21].Concerns about whether the initial investment is justifiable arise when challenges such as uncertain data quality and unresolved cybersecurity issues remain [25]. The data collected can be noisy and poses the risk that no reliable predictions can be made [25], which greatly affects the PdM systems effectiveness.

4.3.3.1 Cybersecurity

To enable data processing and -analysis, equipment in production facilities requires to be connected to the internet [23]. This comes with a risk of cyber-attacks, where vital information about the production can be stolen and used to compromise future work and revenue.
New policies must be created to mitigate this risk, but data will never be as secure as if it were completely offline [27]. The increase of risk for cyber attacks demand investment in cyber security [38]. This increases the demand on both workers and the technology, when security alerts and updates needs to be managed on top of other tasks.

4.3.3.2 Data management and -storage

With the implementation of PdM in production environments rises the challenge to integrate a traditionally offline manufacturing site with the world of IT [21]. Manufacturing requires to be more digitalised to benefit from the new technology emerging as a part of Ind4.0, but it is not easy to get there.
Issues such as change in equipment characteristics can affect the relevance of previously collected data [24], leading to problems every time a change is required. The dynamic environment of a manufacturing industry also makes it difficult to collect reliable data, compromising the created predictions [24]. To mitigate the risk multiple data collection tools can be used to offer better predictions [25], which on the other hand adds to the cost of implementation.

Another issue can be to ensure that the collected data is recognised the same as commonly known knowledge. As data driven decision making is not as common within maintenance [26]. Making it hard to allow for data analysis issue when the resistance towards the technology is already present.

4.3.3.3 Knowledge-gap

The operators and maintenance personnel can have inadequate knowledge about a PdM system and therefore impact the benefits gained from using it [22]. That makes it essential to have a strategy for educating the personnel. With lacking knowledge in the organisation, risk of dependence on external parties or major production stoppages can occur if problems arises connected to the PdM system [22].

A knowledge gap can also be reason for the maintenance personnel to not trust the data being collected [39]. Leading to an insufficient way of working, opposite to the intention with implementing a PdM- system.
Using PdM also require the workforce to have a certain skill set in data analysis and a deeper understanding of how the particular equipment work. The workers will also need to have a understanding of PdM and its limitations and advantages to be able to operate it efficiently [39]. Forcing a new way of working, which can be challenging to adapt.

PdM systems have mostly been used in a experimental or limited production environment. It can be a challenge for maintenance workers to fully implement the systems in a running production setting, especially when disruptions and unknown problems can occur during upscaling [25]. The importance of accuracy of the PdM-system increases, as more data is collected. This is done by validating the data to ensure that the virtual representations is a realistic representation of reality [27]. It can otherwise lead to inaccurate predictions, which can compromise safety and productivity [27].

4.3.4 Research gap

Comparing different methods for decision making algorithm is highly researched, but leaves the consequences of PdM undiscovered. This research covers the benefits and challenges with PdM, while leaving the functionality of the system outside the scope. By basing the research on a already functional platform allows for discovering how data-driven decisions can affect the maintenance actions within a production system. Exploring the topics that are lacking scientific exploration.
Most of the research within PdM is isolated to a specific equipment or a part of a experimental set-up [25]. Figure 4.7 shows the share of PdM research that is performed in a experimental- or industrial setting, showing a bias towards experimental setups. While these setups are useful for exploring specific topics, they lack relevant information when not an entire system is explored.

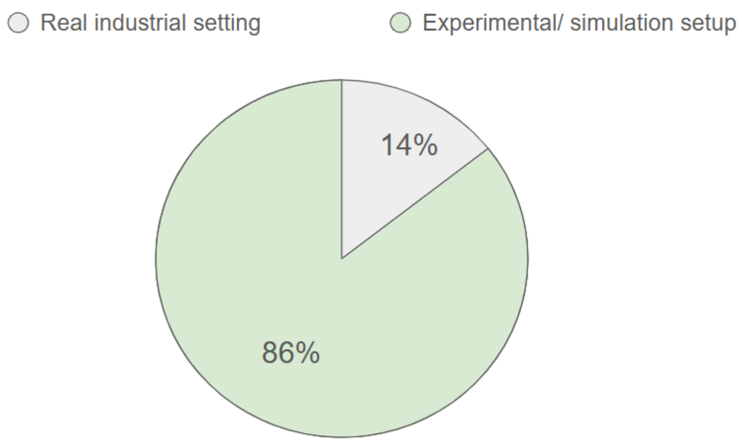


Figure 4.7: Predictive maintenance division, based on [25]

Companies can be more resilient towards PdM when the research has not covered how it impact a production line. Opening up for a lot of unknowns about PdM in a scaled up version. This can lead to lacking knowledge about PdM´s impact on the entire productions chain, missing out on information that might impact the decision to implement it.
This leaves out how manufacturing sites can adapt the technologies within Ind4.0 and test how they are working together with the other equipment. PdM is a part of digitalising manufacturing industries, leading to unknown effects on the running production which has yet to be discovered. This research has the possibility to fill these research gaps by exploring topics from a new angle.

5

Results

5.1 questionnaire answers

The answers collected in the questionnaire generated some quantitative data. The result is shown in the following section, divided into topics collected from the answers. The questionnaire questions can be seen in appendix B.

5.1.1 Company size

One of the questions covered the number of employees at each company, which was included to give insight into the sample group. This was necessary as the sample group was not defined by company size, making it important to identify which types of companies the results would apply to. Figure 5.1 shows the distribution between the different alternatives that each respondent could chose from.

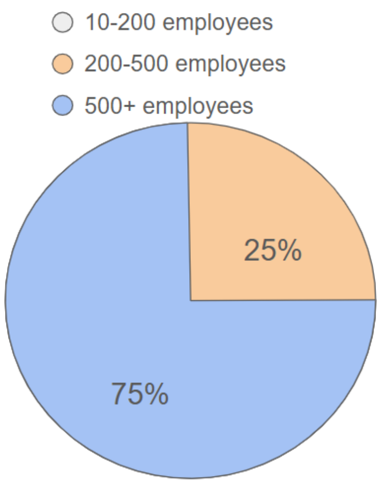


Figure 5.1: Company size in the sample group

75 precent of the answers stated that they belonged to a organisation that were 500 employees or more. 25 precent was 200 to 500 employees, while 0 precent answered that they was part of a organisation with 10-200 employees. This showed a majority of the responders were from larger companies. This shows a bias in the sample group, making the answers mostly relevant for bigger organisations.

5.1.2 Criticality of KUKA robots in customers current production

The question gave insight into how crucial the KUKA robots are to the customers production. The rating goes between 1 to 5, were 1 was the robots not being important for the daily running, while 5 was that the production would halt without them. Figure 5.2 shows the average opinion between all answers.

Figure 5.2: Criticality of KUKA robots in customers current production, average of all responses

The result highlight that the KUKA robots are a vital part of the responders production. It also indicates that the robots are located in process critical places of the production.

5.1.3 Current conditions to use iiQoT

Some of the questions were used as indications to how the responders current condition was and if they had the ability to implement iiQoT. The questions gave a view of their current attitude and was used as a reference when analysing the questions about potential barriers further down.

Figure 5.3 displays the share of responders that are currently using the different versions of iiQoT. The advanced version contains the PdM tool, while basic can only monitor the current state of the robots. Both versions requires the same integration and only difference being an extra cost to get iiQoT.Advanced.

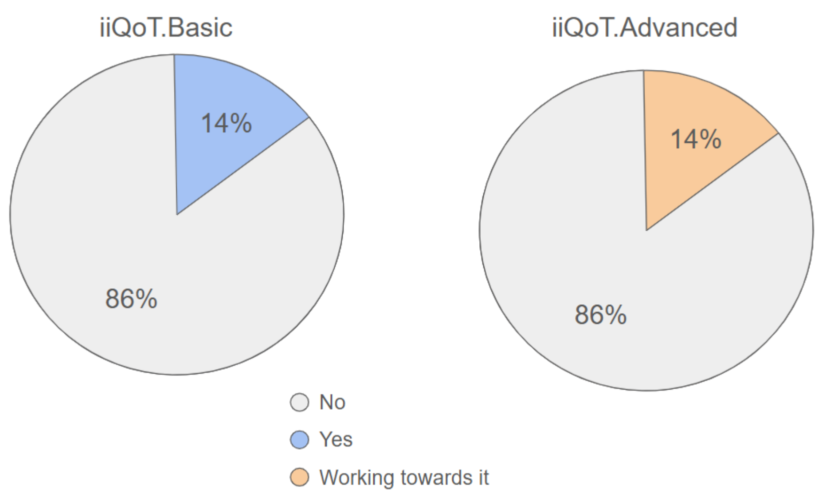


Figure 5.3: Customers current use of the iiQoT platform

A customer already using iiQoT.Basic is more likely to adopt iiQoT.Advanced compared to one without any connected robots. The answers clearly shows that the majority of the responders are not using either of the iiQoT versions nor planning to do so in the future.

One question asked how much the customers production relies on Ind4.0 principles. The response is shown in Figure 5.4, which displays a rating on a scale from 1 to 5, where 1 indicates "not at all" and 5 indicates "fully". The answer represents the average of all responses.

Figure 5.4: Customers use of Industry 4.0 principle in their production, average of all responses

The answers show that most responders use Ind4.0 principles in their production. This shows that the customers are aware and using digitalised solution in their current production, giving them the right conditions to expand in that work.

It was also asked weather the customers was currently using PdM in their production, not specifying in what extent or on what equipment. Figure 5.5 shows the share of responders that currently used it and not. The question was a simple yes or no, not disclosing if any customer was in an implementation stage.

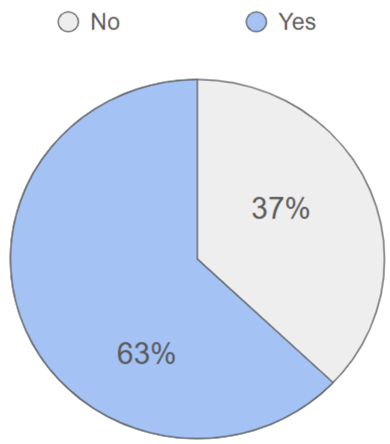


Figure 5.5: Customers use of predictive maintenance in current production

More than half of the responders declared that they are currently using PdM somewhere in their production. This together with the data from figure 5.4 shows that the responders uses cutting edge technology to improve their production, giving them good conditions to implement PdM on their KUKA robots.

5.1.4 PdM to reduce environmental impact

Those responders that indicated that they were currently using PdM as part of their maintenance strategy got a follow up question regarding if they used it as a way to lower their environmental impact, figure 5.6 shows how they answered.

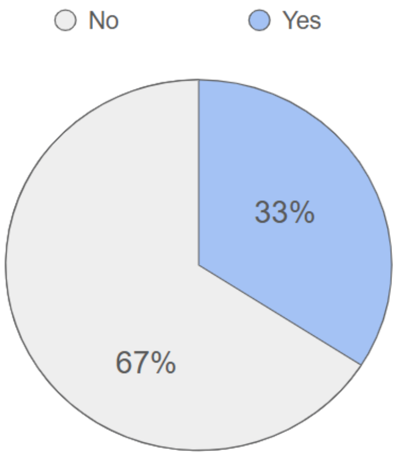


Figure 5.6: Customers use of predictive maintenance to reduce sustainability impact

The SLS showed in 4.3.2.1 *Environmental impact* that PdM is a good tool for lowering a plant´s environmental footprint. While the answers in the questionnaire states that a majority do not use PdM for sustainability purposes.

5.1.5 Barriers

The potential barriers were presented to the respondents to ensure that a relevant analysis could be conducted based on the results. This approach was necessary due to the limited sample size, which posed a risk of low correlation between responses and could have led to a result hard to interpret. Figure 5.7 shows what the responders believed was a barrier and not. The result is an average of all answers and was ranked between 1 to 5, where 1 meant that it was not a barrier and 5 meant a big one.

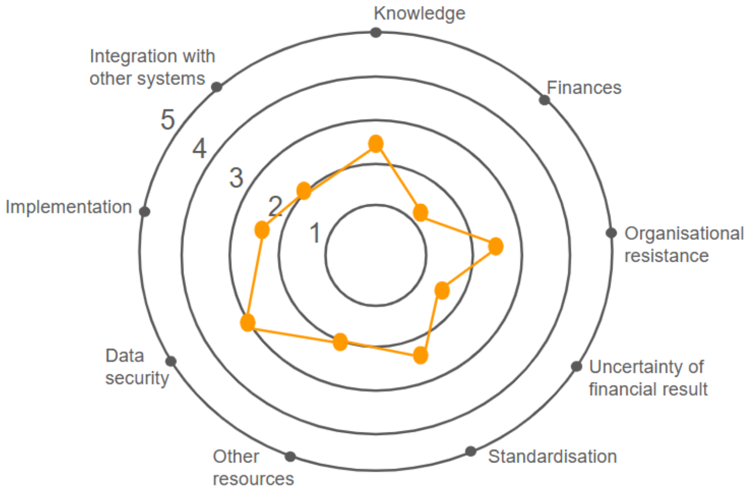


Figure 5.7: PdM implementation barriers for iiQoT according to customers

Most of the barriers was placed between 1 and 2, meaning that it is a small barrier, on the edge to not an barrier at all. No potential barrier was categorised above a 3, showing that there is no single reason for why the customers choose to not use iiQoT. "Data security", "knowledge", "organisational resistance" and "standardisation" is slightly higher ranked than the rest. Making them relevant to evaluate further.

5.1.6 KUKA´s ability to assist customers in overcoming barriers

The last question asked was if KUKA could help the customers overcome any of the stated barriers. The result was an average of all answers and the ranking was between 1 and 5, were 1 was that KUKA could not help them at all and 5 was that KUKA could definitely help.

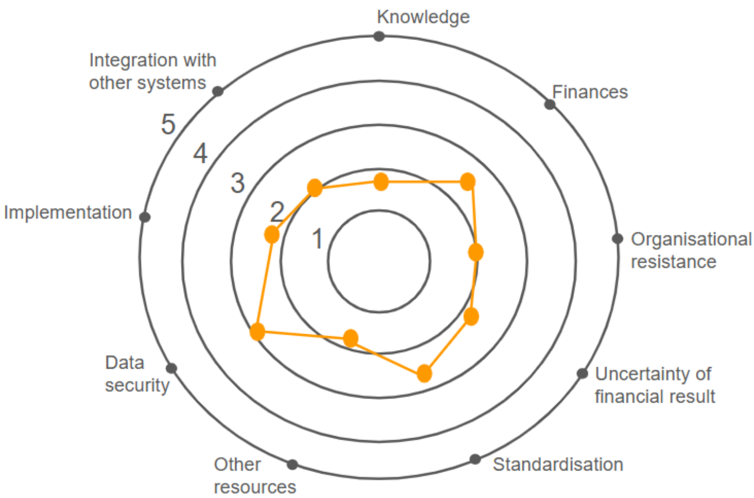


Figure 5.8: PdM barriers for iiQoT that KUKA can help the customer overcome

Most of the barriers was placed around 2, meaning that KUKA cannot assist them in overcoming these barriers according to the customers. The ones that was higher than the rest included "data security" and "standardisation", which was also stated as two of the biggest barriers.
Together with "finances", which was stated as a 1 and therefore not a barrier at all. While "knowledge" which was stated as one of the biggest barriers, was not classified as something KUKA could help them overcome.

5.1.6.1 Comparison with KUKA´s answer

A representative from KUKA answered the same question to compare their response with the customer's, while also evaluating the barriers KUKA believes they can help the customer overcome. The comparison between KUKA and the customers responses can be seen in figure 5.9.

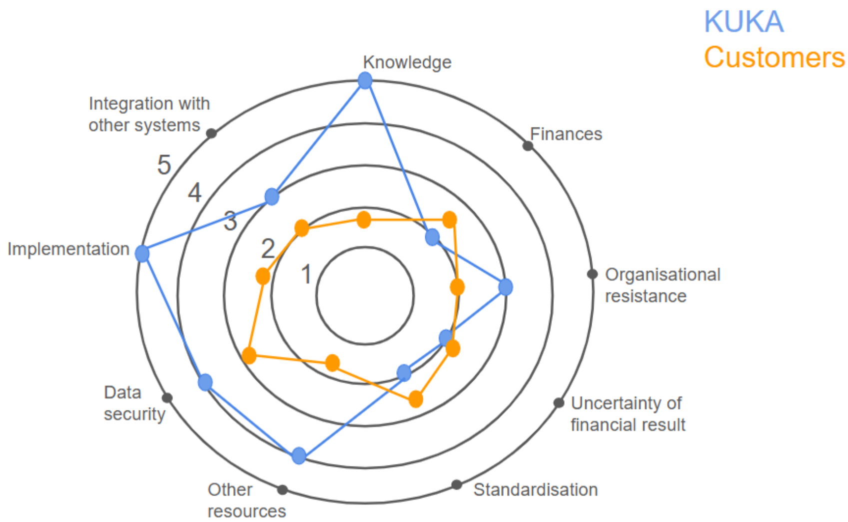


Figure 5.9: PdM barriers for iiQoT that KUKA can help the customer overcome compared to what KUKA believe they can help the customers with

The most notable differences is for the barriers "other resources", "implementation" and "knowledge", were KUKA believe that they can assist their customers in a much higher extent then what the customers do. While KUKA have a lower ranking for the barriers "finances", "standardisation" and "uncertainty of financial result". Meaning that the customers think that KUKA can help them more than what KUKA believes. The answers is quite similar but KUKA have ranked higher for the barriers "data security", "integration" and "organisational resistance". Leading to believe that the customers and KUKA have a quite similar view, but as seen in most of the other answers- KUKA think that they can help more than what the customers think. Indicating that the customers have little awareness of how KUKA can assist them in overcoming barriers. Something that KUKA need to change to get more organisations to use iiQoT and their PdM tool.

5.2 Codes identified from interviews

The conducted interviews generated data that were analysed. Codes were identified and combined, which made code categories. Figure 5.10 shows all codes and code categories generated from the interviews.

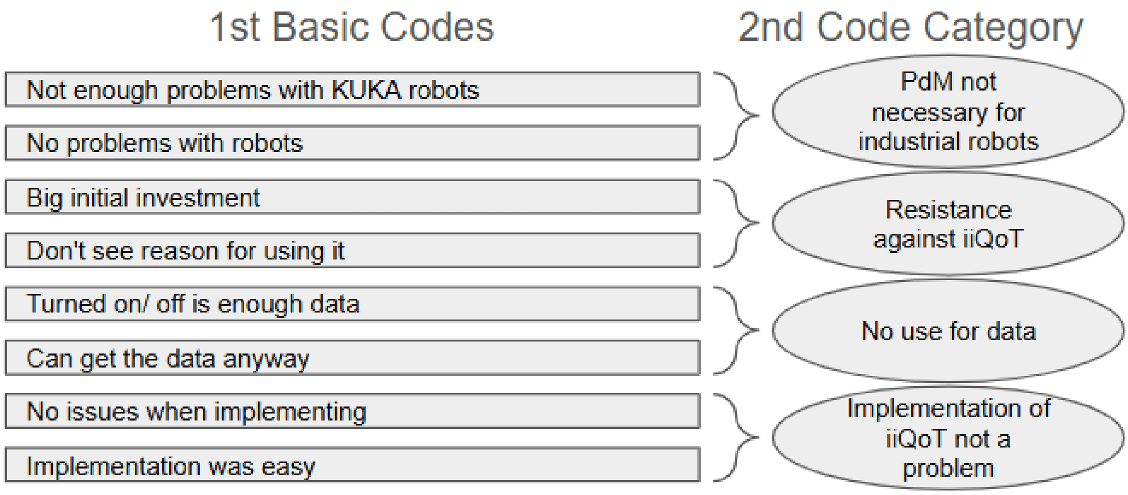


Figure 5.10: Data structure for interviews

5.2.1 Not enough failures related to the robots

One reason mentioned in several interviews for not implementing PdM on KUKA's industrial robots was that the robots do not break down frequently enough to justify the investment. They experience that the robots is rarely the reasons for stoppages in production. Instead, tools connected to the robots or machines interacting with the robots have more pressing problems. As a result, the cost of implementing the necessary infrastructure for PdM, along with the subscription fee for the iiQoT platform, is not considered a worthwhile investment. The result from this is a overarching preference to use reactive maintenance on KUKA´s robots, due to the long periods without failures or stoppages.

5.2.2 No use for the collected data

The interviews also showed that the data collected via iiQoT.Basic is enough for the customers to monitor their production. The customers were overall happy with knowing if every robot is either turned on or off, making the iiQoT.Advanced and PdM tool unnecessary. The improvement from having no connectivity to being able to access the status of each robot is sufficient to meet most customers' needs, reducing the time spent checking robot availability.
The data collected while using PdM can be overwhelming and hart to manage, increasing the demand on the maintenance staff, especially on those companies with hundreds of robots. The storage and management of the collected data is to much work to justify implementing PdM according to some customers.

5.2.3 No issues to implement iiQoT

Some of the interviewed companies was already or had been connected to iiQoT. Their experience with the implementation was overall positive. The steps included was to set up a local network, then connect the robots and the iiQoT platform. The impression was that the implementation was a simple task and the only problems mentioned was related to internal delays before the network could be created.
The information and instructions provided by KUKA to assist the implementation was sufficient and the customers did not experience any need for further assistance.

5.2.4 Resistance against iiQoT

The interviews highlighted the overall resistance against iiQoT and PdM on their KUKA robots. Some mentioned that they already had similar tools for scheduling and coordinating maintenance task, making them not feel the need to use another system as well. Some explained that they already had PdM systems, while others used time-based maintenance instead. Either way, they emphasized a satisfaction with their current systems and mentioned that KUKA´s iiQoT would be redundant with their current set-up. iiQoT does not fill any gap in the maintenance activities and is therefore seen as a burden more than a tool.

Another reason brought up was that they did not see the financial return of the investment. Taking the initial investment to integrate iiQoT, the subscription cost for the platform, pay for the maintenance staff to monitor the tool in relation to the fact that their robots do not have failures that frequently. Then they claim that it is more cost effective to fix the robots that fails, even though spare-parts are costly and repairs can delay production.

5.3 Key takeaways

The combined takeaways from the systematic literature study and the qualitative study was evaluated and presented in this section.

5.3.1 Identified barriers

The graph shown in figure 5.11 is based on the answers in the qualitative study and the information gathered in the systematic literature study. It consists of the potential barriers for implementing PdM. The y-axis shows if KUKA already provides the solution to the problem or if they need to develop a new feature to do so. The x-axis presents if the difficulty to overcome the barrier is small or big. The four squares represents categories with different criticality, were 1 is low and 4 is high. The ‘provides-small´ square consists of barriers that are covered by the current iiQoT platform with low criticality. While the ‘develop-big´ square requires KUKA to provide new solutions to fix major problems that are keeping the customers from implementing PdM and are therefore higher criticality.

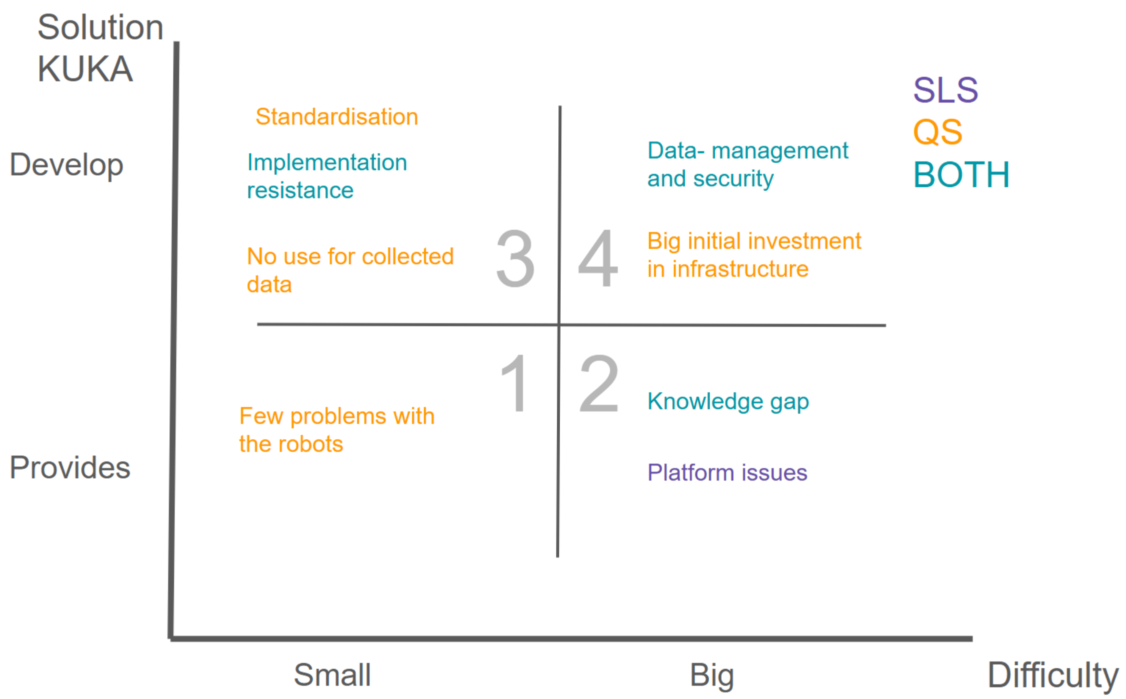


Figure 5.11: Barriers to implement PdM, divided between source

Systematic literature study

Some of the barriers identified through the SLS is covered by the iiQoT platform. "Platform issues" and "knowledge gap" is all solved by the robots and the platform being integrated before being sold to the customers, together with the extensive learning material provided by KUKA. It makes things easier for the customer as decisions that requires insight into the equipment is already handled during development. There is no unnecessary complexity as the platform is already developed and seamlessly integrates with the robots, making data management less complex and ensuring that testing during a longer period of time is already covered before being installed.

The barriers that KUKA do not cover and therefore need to react to is "data- management and security", and lacking support in the implementation. If these aspect would be covered, a wider range of customers could benefit from iiQoT.

Qualitative study

The barriers discovered through the qualitative study is applied to iiQoT specifically and have therefore more relevance than those generated through the SLS. A barrier mentioned was that the KUKA robots does not have enough failures for PdM to be worth investing in, which is classified as a small barrier, as KUKA never would make their products worse to benefit the use of PdM.
"Lacking knowledge" was also mentioned in the qualitative study as a barrier, but KUKA already provides information about their PdM system and those customers with experience from using iiQoT think it is enough.

Smaller barriers identified was "standardisation" and "no use for the collected data". These requires action from KUKA to overcome, but are not deemed the most critical. "Data- management and security" was mentioned in the qualitative study as well and together with "big initial investment in infrastructure" belongs to the most critical barriers. Both is keeping the customers from implementing PdM on their robots, the initial investment making them resilient towards trying and see how it works. While the security and management issues surrounding the data is mostly due to fear of cyber interference and increased cost related to data storage.

5.3.2 Resistance towards iiQoT while having the right conditions

The answers in the questionnaire, shown in 5.1 *questionnaire Answers* explains that the responders do not experience any big barriers hindering them from using iiQoT. Most have the right conditions for using iiQoT, with an established Ind4.0 mindset in the maintenance department. A majority of the responders did also already use PdM as part of their maintenance strategy, giving them insights into the requirements and infrastructure needed.
Regardless, the majority answers that they do not intend on implementing iiQoT on their industrial robots in the near future. Reasons mentioned being that they have no need for all collected data and that they do not experience enough failures on their KUKA robots. Explaining that most issues is related to the tool or machines that the robot is interacting with, making the robot a lower priority to invest in preventive measures.

6

Discussion

6.1 Impressions of result

The results show that the respondents do not consider iiQoT and PdM for their industrial robots as it do not offer enough benefits to justify an investment. This is contradicting to other research, which claims the total opposite with major cost savings in reduced failures and material damage [27].
The result also shows that most of the organisations asked has the right conditions to implement iiQoT, but decides against it anyway. It can be due to industrial robots being a mature equipment type and have been iterated over multiple years without changing drastically. Leading to a well functioning product that does not require a lot of maintenance in the first place, which aligns the answers in the qualitative study.
However, some areas could still benefit from using PdM, such as robots in production critical positions or programmed to do repetitive limited movements, which according to experts at KUKA could shorten the lifespan of the industrial robots. This aligns with other research, which claims that PdM is useful on equipment that would majorly affect the productivity with a failure [37].

6.1.1 Deviations between systemic literature study and qualitative study

Some of the topics discovered in the SLS aligned with the findings in the qualitative study. Other aspects were completely contradictory, such as opinions on which equipment PdM is most effective for. The literature in the SLS did not cover this topic in detail, but it was presented that PdM is suitable for expensive equipment [38]. Meanwhile, the participants in the interviews explained that they did not find PdM on industrial robots relevant, as failures rarely occurred. This contradiction may have several explanations, but more expensive equipment is generally expected to undergo extensive testing and therefore operate without disturbances. However, in the event of a failure, the consequences can be severe, requiring costly spare parts and complex repairs that may affect overall productivity.

Another reason could be that this thesis covers a specific type of equipment, which may not be the most suitable when connected with PdM. While the literature in the SLS investigates PdM on a full production, without considering which types of equipment gain the most from using PdM and which could achieve similar improve-

ments through other more established maintenance strategies.
The interview answers can also deviate as they might consider KUKA´s customer service, making their responses biased by previous experiences. The answers could therefore be different if other companies was participating in the interviews.

6.1.2 Bias in sample group

The result shows that the sample group was biased towards larger organisations, making the recommendations mostly relevant for them. This was not included as a criteria when selecting the sample universe and was discovered during analysis of the answers of the questionnaire.
This bias may be because larger organizations have employees with the expertise that was required to participate in the qualitative study, which was not considered in advance. Therefore, the study is limited and does not fully represent KUKA's entire customer base. Further mapping is needed to determine which organizations this thesis is relevant to.

The results indicates that a sample group limited by the size of organisation can get a different result from the one in this thesis. The customers included in the sample group had already established maintenance systems, which made them resilient to implement another system in their daily work.
By doing the same investigation with another sample group with a smaller maintenance department, could potentially see great value in using a finished platform as iiQoT. Where no complicated set-up or development is needed, making it more suited for companies with no need for customisation. This is something that was not covered in this thesis and should therefore be investigated further.

6.1.3 PdM as a tool to lower environmental impact

The main finding from the qualitative study was that few participants use PdM to reduce their environmental impact. The interviews discovered that environmental sustainability was not a parameter that they considered when selecting maintenance actions.
This could explain why the respondents were hesitant to implement iiQoT. It might not be a significant improvement when only considering the financial aspects. However, by including environmental impact as a criterion when considering maintenance actions or strategies, the outcome might be different[41]. Especially when improved environmental sustainability is one of the main benefits with PdM according to the SLS. By not considering the possibility to lower the environmental impact when deciding maintenance strategy, allows for misconceptions about the usefulness of PdM and act as a possible explanation for the result of this thesis.

6.1.4 Small sample size in qualitative study

The sample size was limited to 3 interviews and 17 questionnaire responses. To accommodate this, the sample group was selected to include individuals working in maintenance or automation with prior knowledge of PdM. This ensured that all

answers were relevant to the topic, making it less necessary to have a large sample group.
The thesis also included a systematic literature study to accommodate for potential information-gaps in the qualitative study. The SLS was also used when creating the questions for the questionnaire, ensuring that saturation was reached with fewer occasions to collect data.

6.2 Recommendations

The result identified barriers preventing KUKA´s customers from implementing PdM on their industrial robots. This section will go deeper into what KUKA can do to increase the interest among their customers for the iiQoT platform and specifically the PdM tool. Some recommendations are directed towards KUKA´s customers and covers what they can do to ensure a successfully PdM implementation.
Figure 6.1 shows the barriers from 5.3 *Key takeaways* and their ranking from in figure 6.1. Each barrier has their respective recommendation and implementation approach. Some barriers share the same recommendation, while others have separate ones.

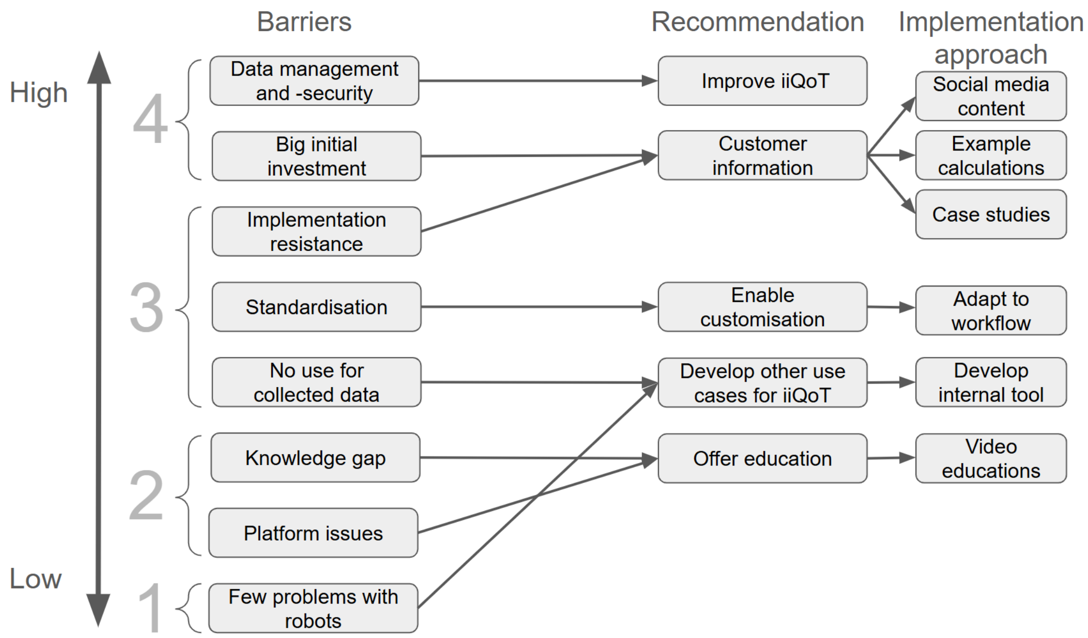


Figure 6.1: Framework with recommended actions to overcome barriers for PdM

The only barrier that can be addressed by improving the iiQoT system is "data-management and security". The customers stated this as one of the most crucial problems that needs to be solved. This thesis does not go into the development of iiQoT and can therefore neither give any implementation suggestions nor verify if the statement is true or not, just that this is a reason brought up during the study. If can confirm KUKA´s that no improvements are needed, instead the recommendation is to share more information with the customers regarding this specific topic, as that is currently not present in their advertisement. The study also confirms that such information have not been received by the customers.

To share more information with the customers is required to overcome the barriers "big initial investment" and "implementation resistance". The interview responses indicate that organisations which have implemented iiQoT have not experienced any problems, suggesting that the resistance is likely due to a lack of information about the implementation process. Awareness can be increased through social media content that showcases iiQoT and the implementation process, for example by sharing customer interviews about their experiences.
According to experts at KUKA, the initial investment is relatively small compared to prices of spare parts. That customers acknowledge this as a barrier shows the lack of information provided by KUKA. Recommended is to create example calculations or outcomes from case studies, to show what the actual cost can be to connect a robot to iiQoT.

The customer´s problems with standardisation may be related to KUKA´s inability to adapt iiQoT to their specific workflows. KUKA can assist by enable the customers to customise the iiQoT platform and adapt it to their internal standards.
Some customers do not have the resources to manage all data collected through iiQoT. Leading to data being stored without coming to use. iiQoT might not be ideal for all types of companies, despite the system having reliable predictions. KUKA can instead use the PdM tool to create different business cases to accommodate for lacking interest.
This can also be done to mitigate the barrier created when the robots do not experience enough failures that could be predicted by iiQoT. This is not a problem, but still a reason customers decides against implementing iiQoT. KUKA can develop the iiQoT platform to also be used as a internal tool, to lower cost by only performing service on industrial robots that requires it.

Recommended is also to offer more education about how iiQoT works and should be used, which can be done through pre-recorded videos or education occasions. This can erase barriers related to customers limited knowledge about the PdM concept, but also to minimise misconception about iiQoT and its use cases. Education occasions, can also act as opportunity to inform customer about the benefits.

6.2.1 KUKA

iiQoT is a well-functioning platform, and the barriers identified in this thesis are not related to its functionality, but rather to other external factors. iiQoT offers all components required for an effective PdM system, but KUKA can take some certain actions to increase the number of users.
KUKA need to create incentives for customers to use iiQoT, which can be done through including it in their service agreement or by offering test-periods with free or discounted price. This will allow customers to test the iiQoT platform, experience its benefits, and consider them when deciding whether to invest.

Most barriers emerges from misconceptions and can be mitigated with more information about the positive impact of iiQoT, but also PdM in general. The customer can make a more informed decision, if provided with insights into the sustainability and productivity improvements of using PdM. It is unlikely that the customers will implement a system without the right knowledge. Informing customers about how PdM can improve the daily operation of their industrial robots is essential for the wider adoption of iiQoT.

This thesis shows that PdM might not give the most improvements when used on industrial robots, but that does not mean that a functioning PdM- analysing tool is to no use. KUKA should use it to create new business opportunities, using it both as an internal tool and as a new solution to offer customers.

6.2.2 KUKA´s customers

iiQoT is a system that most can benefit from using in one way or another. It is not required to be used on all available KUKA robots, but can instead be implemented strategically to get the advantages without an excessive cost. It can be beneficial to identify the most crucial position of the KUKA robots and use it were a failure would be critical to the performance. PdM is a powerful strategy that can reduce stoppages and fatal failures. iiQoT is simple as all the hard integration work is already done, which makes the process simple and worth testing.

The result from the qualitative study showed that few had environmental sustainability as a criteria while evaluating investments for the maintenance department. Some mentioned doing productivity and cost calculation to compare different maintenance strategies, but did indicate that they do not consider environmental sustainability in this process. Taking this into account will most certainly show PdM in a more beneficial way when applied to industrial robots, as PdM can reduce the required spare parts and storage compared to other strategies currently used by the customer.

6.3 Reflections

This section includes other reflections of the thesis that does not specifically surround the result.

6.3.1 Ethical interview process

There is some ethical dilemmas brought with a interview process, which needs to be considered. The interviewee gives up the control over how their responses are interpreted by the interviewer, creating the possibility that the interviewer's understanding may differ from the interviewee's original intent.
The privacy of the interviewee is also something to consider, as that allows them to be transparent about their opinions. This can also reduce the bias in the answers, as the interviewees might feel that it is more comfortable to express their

true insights while being anonymous. This also goes into the confidentiality of the

interviewees organisations, which otherwise might not be comfortable with sharing information about their maintenance methods and how it affect their production. Making anonymity of the participants crucial for the success of this thesis. As it would not be relevant if the participant did not share information that could help answer the research questions.

6.3.2 Limited area of publication in SLS

The descriptive analysis in the systematic literature review shows that a majority of the publications used was published in or around the European region. All continent was represented with one or a few articles each, but the majority was published in Europe. Notable is that no articles from USA or China was present in the SLS, as these countries are known for their research toward digitalised production and efficiency improvements.

One of the reason can be that the search term was limited to "predictive maintenance". This term was founded in Germany as part of the introduction of Ind4.0 and spread when the European Union connected incentives to further research the topic. China uses the term "Made in China" as a representation for the Industry 4.0 concept, while USA uses "Prognostics and Health Management" as a broader concept that includes "predictive maintenance".
A wider range of geographic distribution would probably be present if the other mentioned search terms would have been used. This was not done in this thesis, the reason being to keep the SLS relevant and comparable with the case study company KUKA Nordics, which are based in the Nordic- and Baltic region. Using the other search terms would lead to a wider scope of the topic, but with the risk to include irrelevant information that would harm the thesis overall.

6.4 Future work

The specific sample group in this thesis do not get all benefits of PdM, if compared to the literature. There are suspicions that a different sample group consisting of smaller organizations could lead to a different result. A study should be done to verify the suspicions, as this thesis only got implications that another sample group would get more benefits. A study like that should be carried out in a similar manner to the one covered in this thesis, to ensure that the results are comparable.

It could also be interesting to do a case study with one of KUKA´s customers to see the effects of implementing PdM on industrial robots. The result in this thesis is only based on the information provided by the customers through the interviews and questionnaire. Meaning that the information provided could not be verified, which creates error sources for the thesis. It would therefore be valuable to do a case study to compare to the result of this study and see the difference between using PdM and not.

It was also discovered that PdM might not be as beneficial as it could be when implemented on industrial robots. This can be due to the maturity of the equipment, as it has been improved without major changes over the last decades.
It would be interesting to do a comparison between the advantages with PdM on different equipments commonly emerging in a production, such as CNC-mill or electric hand tools and comparing it to industrial robots. This would reveal which equipment is most worth to implement PdM on first and which would provide the greatest benefits.

7

Conclusion

The aim of this thesis was to investigate the effects of using predictive maintenance on KUKA robots in a production environment and discover what the potential barriers could be. The thesis discovered that there is multiple benefits with using predictive maintenance and that KUKA could mitigate the barriers keeping customers from implementing it. Instead, factors not connected to KUKA´s PdM system appears as the reason for the customers resistants against PdM on KUKA´s industrial robots. The other main conclusions from this thesis is the following:

- The PdM system requires to be built with three critical components: a method to collect data, an analysis tool and a visual interface. All components are present in KUKA´s own PdM tool, which can be accessed through the iiQoT platform.

- The primary effects of implementing PdM is benefits such as environmental, financial and productivity improvements, while challenges include cybersecurity, data management issues and lacking knowledge of the staff.

- Industrial robots are a mature equipment were predictive maintenance might not be the most ideal approach.

- The customers questioned in this thesis does not benefit the most from using PdM on their industrial robots, as they have established maintenance systems, good collaboration with KUKA, knowledge in-house and big maintenance budgets that allows to use reactive maintenance.

Recommendations to overcome the barriers discovered in the thesis was also presented, including to share more information and knowledge about PdM with their customers. Also, to create multiple use-cases for iiQoT, such as developing internal tools that can be used by the customer-service employees.
Recommended is also for KUKA to investigate other sample groups to see how the outcome deviates from this thesis, as indications show that smaller companies could benefit more from using iiQoT.

Bibliography

[1] Mobley K, An Introduction to Predictive Maintenance, Butterworth Heinemann, 2002

[2] Joseph, D., Gallege, T., Turanoglu Bekar, E. et al (2022). A Predictive Maintenance Application for A Robot Cell using LSTM Model. IFAC-PapersOnLine, 55(19): 115-120.

[3] Karlsson, A., Turanoglu Bekar, E., Skoogh, A. (2021). Multi-Machine Gaussian Topic Modeling for Predictive Maintenance. IEEE Access, 9: 100063-100080.

[4] Z. Çınar, A. Nuhu, Q. Zeeshan, O. Korhan, M. Asmael, and B. Safaei, "Machine Learning in Predictive Maintenance towards Sustainable Smart Manufacturing in Industry 4.0" MDPI, Oct. ä-2020.

[5] Xu, L. D., Xu, E. L., and Li, L. (2018). Industry 4.0: state of the art and future trends. International Journal of Production Research, 56(8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806

[6] KIEL D, MÜLLER M. M, ARNOLD C and VOIGT K, SUSTAINABLE INDUSTRIAL VALUE CREATION: BENEFITS AND CHALLENGES OF INDUSTRY 4.0, International Journal of Innovation Management, Vol. 21, No. 8 (December 2017) 1740015 (34 pages), DOI: 10.1142/S1363919617400151

[7] Oliver Kovacs, The dark corners of industry 4.0 – Grounding economic governance 2.0, Technology in Society, Volume 55, 2018, Pages 140-145, ISSN 0160-791X, https://doi.org/10.1016/j.techsoc.2018.07.009.

[8] Gackowiec P, General overview of maintenance strategies – concepts and approaches. Multidisciplinary Aspects of Production Engineering, Vol. 2, Iss. 1, 126-139. (2019)

[9] Lind, H. and Muyingo, H. (2012), "Building maintenance strategies: planning under uncertainty", Property Management, Vol. 30 No. 1, pp. 14-28. https://doi.org/10.1108/02637471211198152

[10] Karlsson, A., Turanoglu Bekar, E., Skoogh, A. (2021). Multi-Machine Gaussian Topic Modeling for Predictive Maintenance. IEEE Access, 9: 100063-100080. http://dx.doi.org/10.1109/ACCESS.2021.3096387

[11] Tiago Zonta, Cristiano André da Costa, Rodrigo da Rosa Righi, Miromar José de Lima, Eduardo Silveira da Trindade, Guann Pyng Li, Predictive maintenance in the Industry 4.0: A systematic literature review, Computers and Industrial Engineering, Volume 150, 2020, 106889, ISSN 0360-8352, https://doi.org/10.1016/j.cie.2020.106889.

[12] Martina K Linnenluecke, Mauricio Marrone, and Abhay K Singh. Conducting systematic literature reviews and bibliometric analyses, Australian Journal of Management 2020 45:2, 175-194

[13] O. Motaghare, A. Conducting systematic literature reviews and bibliometric analyses Martina K Linnenluecke, Mauricio Marrone, and Abhay K Singh Australian Journal of Management 2020 45:2, 175-194and Computing Research (ICCIC), Madurai, India, 2018, pp. 1-4, doi: 10.1109/ICCIC.2018.8782406.

[14] DiCicco-Bloom, B. and Crabtree, B.F. (2006), The qualitative research interview. Medical Education, 40: 314-321. https://doi.org/10.1111/j.1365-2929.2006.02418.x

[15] Malterud K, Siersma VD, Guassora AD. Sample Size in Qualitative Interview Studies: Guided by Information Power. Qualitative Health Research. 2016;26(13):1753-1760. doi:10.1177/1049732315617444

[16] Robinson, O. C. (2013). Sampling in Interview-Based Qualitative Research: A Theoretical and Practical Guide. Qualitative Research in Psychology, 11(1), 25–41. https://doi.org/10.1080/14780887.2013.801543

[17] Dworkin, S.L. Sample Size Policy for Qualitative Studies Using In-Depth Interviews. Arch Sex Behav 41, 1319–1320 (2012). https://doi.org/10.1007/s10508-012-0016-6

[18] Maria Rosala. How to Analyze Qualitative Data from UX Research: Thematic Analysis, https://www.nngroup.com/articles/thematic-analysis/, NN Group. (2022)

[19] Morteza G, The future of manufacturing industry: a strategic roadmap toward Industry 4.0. Journal of Manufacturing Technology Management. Vol. 29, Issue 6, 910-936. (2018).

[20] Hannah Snyder, Literature review as a research methodology: An overview and guidelines, Journal of Business Research, Volume 104, 2019, Pages 333-339, ISSN 0148-2963, https://doi.org/10.1016/j.jbusres.2019.07.039.

[21] ALEXANDROS BOUSDEKIS, DIMITRIS APOSTOLOU and GREGORIS MENTZAS, Predictive Maintenance in the 4th Industrial Revolution: Benefits, Business Opportunities, and Managerial Implications. IEEE ENGINEERING MANAGEMENT REVIEW, VOL. 48, NO. 1, (2020).

[22] Luminita Ciocoiu, Carys E Siemieniuch and Ella-Mae Hubbard, From preventative to predictive maintenance: The organisational challenge. Journal of Rail and Rapid Transit. 2017, Vol. 231(10) 1174–1185

[23] M. Ayala-Chauvin, F. Avilés-Castillo, D. Yánez-Arcos and J. Buele, "Predictive Maintenance in Industrial Robotics Using Big Data: Techniques, Challenges, and Opportunities" 2024 IEEE Eighth Ecuador Technical Chapters Meeting (ETCM), Cuenca, Ecuador, 2024, pp. 1-5, doi: 10.1109/ETCM63562.2024.10746033.

[24] Julio Hurtado, Dario Salvati, Rudy Semola, Mattia Bosio and Vincenzo Lomonaco, Continual learning for predictive maintenance: Overview and challenge, Journal of Intelligent Systems with Applications. (2023).

[25] Hassana Mahfoud1, Oussama Moutaoukil, Mohammed Toum Benchekroun and Adnane Latif, Real-Time Predictive Maintenance-Based Process Parameters, International Conference on Advanced Intelligent Systems for Sustainable Development, Advanced Intelligent Systems on Energy, Environment and Agriculture, Volume 2. (2023).

[26] Anwar Meddaoui, Mustapha Hain and Adil Hachmoud, The benefts of predictive maintenance in manufacturing excellence: a case study to establish reliable methods for predicting failures, The International Journal of Advanced Manufacturing Technology (2023) 128:3685–3690, https://doi.org/10.1007/s00170-023-12086-6

[27] Fawaz S. Al-Anzi, Abdullah F. Al-Anzi and Sumi Sarath, Proceedings Volume 13188, International Conference on Medical Imaging, Electronic Imagin2023g, Information Technologies, and Sensors (MIEITS 2024); 131880C (2024) https://doi.org/10.1117/12.3030667

[28] Henrik Hviid Hansena, Murat Kulahcib and Bo Friis Nielsenb, A primer on predictive maintenance: Potential benefits and practical challenges, 2024, VOL. 36, NO. 3, 638–649 https://doi.org/10.1080/08982112.2024.2331140 (2024)

[29] A. Cachada et al., "Maintenance 4.0: Intelligent and Predictive Maintenance System Architecture," 2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA), Turin, Italy, 2018, pp. 139-146, doi: 10.1109/ETFA.2018.8502489.

[30] Hoffmann, M.A., Lasch, R. Unlocking the Potential of Predictive Maintenance for Intelligent Manufacturing: a Case Study On Potentials, Barriers, and Critical Success Factors. Schmalenbach J Bus Res 77, 27–55 (2025). https://doi.org/10.1007/s41471-024-00204-3

[31] Pech, M, Vrchota, J, Bedná ˇr, J. Predictive Maintenance and Intelligent Sensors in Smart Factory: Review. Sensors 2021, 21, 1470. https://doi.org/10.3390/s21041470

[32] Attila Katonaa and Peter Panfilov. Building predictive maintenance framework for smart environment application systems, International DAAAM Symposium on Intelligent Manufacturing and Automation, Volume 29, Issue 1, Pages 0460 - 0470. (2018).

[33] Van Cuong Sai, Maxim V. Shcherbakov and Van Phu Tran, Data-driven framework for predictive maintenance in industry 4.0 concept, Communications in Computer and Information Science, Volume 1083, Pages 344 - 3582019 3rd Conference on Creativity in Intelligent Technologies and Data Science. (2019)

[34] Suraj Gupta, Akhilesh Kumar and Jhareswar Maiti, A critical review on system architecture, techniques, trends and challenges in intelligent predictive maintenance, Safety Science, Volume 177, (2024)

[35] Unai Izagirre, Imanol Andonegui, Itziar Landa-Torres and Urko Zurutuza , A practical and synchronized data acquisition network architecture for industrial robot predictive maintenance in manufacturing assembly lines, Robotics and Computer-Integrated Manufacturing, Volume 74 Article number 102287, (2022)

[36] G. Nota and A. Toro, A framework for unsupervised learning and predictive maintenance in Industry 4.0, International Journal of Industrial Engineering and Management Vol 15 No 4 (2024)

[37] DANIEL KIEL, JULIAN M. MÜLLER, CHRISTIAN ARNOLD and KAI-INGO VOIGT, SUSTAINABLE INDUSTRIAL VALUE CREATION: BENEFITS AND CHALLENGES OF INDUSTRY 4.0,International Journal of Innovation Management Vol. 21, No. 8 (December 2017) 1740015 (34 pages)

[38] Achouch, M.; Dimitrova, M.; Ziane, K.; Sattarpanah Karganroudi, S.; Dhouib, R.; Ibrahim, H.; Adda, M. On Predictive Maintenance in Industry 4.0: Overview, Models, and Challenges. Appl. Sci. 2022, 12, 8081. https://doi.org/10.3390/app1216808

[39] Marcel André Hoffmann and Rainer Lasch, Unlocking the Potential of Predictive Maintenance for Intelligent Manufacturing: a Case Study On Potentials, Barriers, and Critical Success Factors, Schmalenbach Journal of Business Research 77:27–55, (2025)

[40] Zeki Murat Çınar, Abubakar Abdussalam Nuhu, Qasim Zeeshan, Orhan Korhan, Mohammed Asmael and Babak Safaei, Machine Learning in Predictive Maintenance towards Sustainable Smart Manufacturing in Industry 4.0, MDPI (2020)

[41] Mohd Javaida, Abid Haleema, Ravi Pratap Singhb, Rajiv Sumanc and Ernesto Santibañez Gonzalez, Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability, Sustainable Operations and Computers 3, page 203-2017,(2022)

[42] Wondimagegn Mengista, Teshome Soromessab and Gudina Legeseb, Method for conducting systematic literature review and meta-analysis for environmental science research,v MethodsX, (2019)

[43] Abdul Karim Feroz, Hangjung Zo and Ananth Chiravuri, Digital Transformation and Environmental Sustainability: A Review and Research Agenda, Sustainability 2021, 13, 1530. https://doi.org/10.3390/su13031530

A

Questions for each interview

Interview 1
Describe your attitude towards Predictive Maintenance?

What are the most common failures or disruptions on your KUKA robots?

Why don´t you use PdM now?

Why do you want to use it?

Can KUKA as a supplier assist you in an implementation? How?

Interview 2
Can you describe your experience with predictive maintenance systems so far?

How does PdM system impact your maintenance strategy?

How do you balance the financial investment versus benefit of adopting PdM?

How easy or difficult is it for your company to adopt new technologies like iiQoT?

How does your company align maintenance strategy with broader sustainability goals?

What would need to change internally for your company to fully adopt predictive maintenance?

Do you think your company will eventually move toward predictive maintenance? Why or why not?

Why have you decided to not use PdM on your KUKA robots?

What would make you reconsider and invest in a system like iiQoT?

How would you have liked KUKA as a supplier to assist you in an implementation?

Have you received enough information or support from KUKA regarding iiQoT?

What would you need from KUKA to feel confident in adopting iiQoT?

Interview 3

Can you describe your experience with predictive maintenance systems so far?

How does PdM system impact your maintenance strategy?

How do you balance the financial investment versus benefit of adopting PdM?

How easy or difficult is it for your company to adopt new technologies like iiQoT?

How does your company align maintenance strategy with broader sustainability goals?

What would need to change internally for your company to fully adopt predictive maintenance?

Do you think your company will eventually move toward predictive maintenance? Why or why not?

Why have you decided to not use PdM on your KUKA robots?

What would make you reconsider and invest in a system like iiQoT?

How would you have liked KUKA as a supplier to assist you in an implementation?

Have you received enough information or support from KUKA regarding iiQoT?

What would you need from KUKA to feel confident in adopting iiQoT?

B

Questions in the questionary

Questionaire about Predictive Maintenance

This questionaire is a part of a thesis work at Chalmers university of technology within the master's program Production Development. The purpose is to investigate KUKA Nordic's customers attitude towards Predictive Maintenance and whether there is interest in implementing it on their KUKA robots.

About you

1. What is your name?

2. What is you role in the organisation?

About your organisation

3. Your companys´ name

4. Size of company
   - ○ 10-200 employees
   - ○ 200-500 employees
   - ○ 500+ employees

5. Your main area of industry
   - ○ Automotive
   - ○ Manufacturing and industrial
   - ○ Pharmaceuticals and Healthcare
   - ○ Defense and Aerospace
   - ○ Retail and Logistics
   - ○ Consumer Goods
   - ○ Annat

6. On a scale of 1 to 5, how crucial are KUKA industrial robots to your production process? 1 being not important at all and 5 meaning production would halt without them.

1	2	3	4	5

7. On a scale of 1 to 5, where 1 means not at all and 5 means fully, to what extent does your production rely on Industry 4.0 principles?

1	2	3	4	5

Predictive Maintenance

8. Are you currently using Predictive Maintenance as part of your maintenance plan?

- ◯ Yes
- ◯ No

9. Are you using Predictive Maintenance to lower your environmental impact?

- ◯ Yes
- ◯ No

10. Are you using iiQoT?

	Yes	No	Working towards it
iiQoT.Basic	◯	◯	◯
iiQoT.Advanced	◯	◯	◯

11. Are any of the following factors barriers to implementing Predictive Maintenance on your KUKA robots? Please rate each factor on a scale of 1 to 5, where 1 means it is not a barrier and 5 means it is a significant barrier.

	1	2	3	4	5
Knowledge	◯	◯	◯	◯	◯
Finances	◯	◯	◯	◯	◯
Organizational resistance	◯	◯	◯	◯	◯
Uncertanty of financial results	◯	◯	◯	◯	◯
Standardisation	◯	◯	◯	◯	◯
Other resources (employees, infrastructure, etc)	◯	◯	◯	◯	◯
Data security	◯	◯	◯	◯	◯
Integrating iiQoT with other systems	◯	◯	◯	◯	◯
Implementing iiQoT	◯	◯	◯	◯	◯

12. Do you believe that KUKA can help you overcome the barriers mentioned above? Rate each on a scale of 1 to 5, where 1 means KUKA can definitely help and 5 means KUKA cannot help at all.

	1	2	3	4	5
Knowledge	◯	◯	◯	◯	◯
Finances	◯	◯	◯	◯	◯
Organizational resistance	◯	◯	◯	◯	◯
Uncertanty of financial results	◯	◯	◯	◯	◯
Standardisation	◯	◯	◯	◯	◯
Other resources (employees, infrastructure, etc)	◯	◯	◯	◯	◯
Data security	◯	◯	◯	◯	◯
Integrating iiQoT with other systems	◯	◯	◯	◯	◯
Implementing iiQoT	◯	◯	◯	◯	◯

C

Final batch of used papers in SLS

Title	Arthors names	Publication year	Publication place
Literature review as a research methodology: An overview and guidelines	Hannah Snyder	2019	Norway
A primer on predictive maintenance: Potential benefits and practical challenges	Henrik Hviid Hansena, Murat Kulahcib and Bo Friis Nielsenb	2024	Denmark/ Sweden
Continual learning for predictive maintenance: Overview and challenge	Julio Hurtado, Dario Salvati, Rudy Semola, Mattia Bosio and Vincenzo Lomonaco	2023	Italy
Predictive Maintenance in the 4th Industrial Revolution: Benefits, Business Opportunities, and Managerial Implications	ALEXANDROS BOUSDEKIS, DIMITRIS APOSTOLOU and GREGORIS MENTZAS	2020	Greece
Predictive Maintenance in Industrial Robotics Using Big Data: Techniques, Challenges, and Opportunities	M. Ayala-Chauvin, F. Avilés-Castillo, D. Yánez-Arcos and J. Buele	2024	Ecuador
SUSTAINABLE INDUSTRIAL VALUE CREATION: BENEFITS AND CHALLENGES OF INDUSTRY 4.0	DANIEL KIEL, JULIAN M. MÜLLER, CHRISTIAN ARNOLD and KAI-INGO VOIGT	2017	Germany
Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability	Mohd Javaida, Abid Haleema, Ravi Pratap Singhb, Rajiv Sumanc and Ernesto Santibañez Gonzalez	2022	India/ Chile
Information Technologies, and Sensors	Fawaz S. Al-Anzi, Abdullah F. Al-Anzi and Sumi Sarath	2024	Qatar
A primer on predictive maintenance: Potential benefits and practical challenges	Henrik Hviid Hansena, Murat Kulahcib and Bo Friis Nielsenb	2024	Denmark/ Sweden
he benefts of predictive maintenance in manufacturing excellence: a case study to establish reliable methods for predicting failures	Anwar Meddaoui, Mustapha Hain and Adil Hachmoud	2023	Morocco
Real-Time Predictive Maintenance-Based Process Parameters	Hassana Mahfoud1, Oussama Moutaoukil, Mohammed Toum Benchekroun and Adnane Latif	2023	Morocco
On Predictive Maintenance in Industry 4.0: Overview, Models, and Challenges	Achouch, M.; Dimitrova, M.; Ziane, K.; Sattarpanah Karganroudi, S.; Dhouib, R.; Ibrahim, H.; Adda, M.	2022	Canada
From preventative to predictive maintenance: The organisational challenge	Luminita Ciocoiu, Carys E Siemieniuch and Ella-Mae Hubbard	2017	England
Unlocking the Potential of Predictive Maintenance for Intelligent Manufacturing: a Case Study On Potentials, Barriers, and Critical Success Factors	Marcel André Hoffmann and Rainer Lasch	2025	England
A critical review on system architecture, techniques, trends and challenges in intelligent predictive maintenance	Suraj Gupta, Akhilesh Kumar and Jhareswar Maiti	2024	India
"Maintenance 4.0: Intelligent and Predictive Maintenance System Architecture	A. Cachada	2018	Portugal
Predictive Maintenance and Intelligent Sensors in Smart Factory: Review	Pech, M, Vrchota, J, Bedná˘r	2021	Czech Republic
Building predictive maintenance framework for smart environment application systems	Attila Katonaa and Peter Panfilov	2018	Austria
Data-driven framework for predictive maintenance in industry 4.0 concept, Communications in Computer and Information Science	Van Cuong Sai, Maxim V. Shcherbakov and Van Phu Tran	2019	Russia
A practical and synchronized data acquisition network architecture for industrial robot predictive maintenance in manufacturing assembly lines	Unai Izagirre, Imanol Andonegui, Itziar Landa-Torres and Urko Zurutuza	2022	Spain
A framework for unsupervised learning and predictive maintenance in Industry 4.0	G. Nota and A. Toro	2024	Italy

DEPARTMENT OF INDUSTRIAL AND MATERIAL SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY