



ESCUELA INTERNACIONAL DE DOCTORADO
Programa de Doctorado en Ciencias Sociales

"Organizational and Economic Potential
of a Reliability Engineering Department
for Manufacturing Companies"

Author:

Dipl.-Ing. (FH) Uwe Christian Bußmann MBA

Directores:

Professor Dr.-Ing. Rudolf Jerrentrup

Professor Dr. M^a Mercedes Carmona Martínez

Professor Dr. M^a Vita Zhukova

Murcia, 28 de marzo de 2025



ESCUELA INTERNACIONAL DE DOCTORADO
Programa de Doctorado en Ciencias Sociales

"Organizational and Economic Potential
of a Reliability Engineering Department
for Manufacturing Companies"

Author:

Dipl.-Ing. (FH) Uwe Christian Bußmann MBA

Directores:

Professor Dr.-Ing. Rudolf Jerrentrup

Professor Dr. M^a Mercedes Carmona Martínez

Professor Dr. M^a Vita Zhukova

Murcia, 28 de marzo de 2025

I. DIRECTORS AUTHORIZATION PAGE



AUTHORIZATION OF THE DIRECTORS OF THE THESIS FOR SUBMISSION

Prof. Dr.-Ing. Rudolf Jerrentrup, Prof. Dr. M^a Mercedes Carmona Martínez, and Prof. Dr. M^a Vita Zhukova as Directors⁽¹⁾ of the Doctoral Thesis “Organizational and Economic Potential of a Reliability Engineering Department for Manufacturing Companies” by Mr. Uwe Christian Bußmann in the Programa de Doctorado en Ciencias Sociales, **authorizes for submission** since it has the conditions necessary for his defense.

Sign to comply with the Royal Decree 99/2011, in Murcia, March 25, 2025.


Prof. Dr.-Ing. Rudolf Jerrentrup


Prof. Dr. M^a Mercedes Carmona Martínez


Prof. Dr. M^a Vita Zhukova

⁽¹⁾ If the Thesis is directed by more than one Director, both of them must sign this document.

II. ACKNOWLEDGMENTS

Writing a doctoral thesis is a project that extends over a long period of time. Such a venture is not possible without the support of many people. The biggest burden was carried by my dear daughter Jill and my dear wife Kerstin, who always supported me, even though they often had to do without me. You deserve my greatest thanks!

I would also like to thank Professor Dr.-Ing. Rudolf Jerrentrup (FOM University, Essen, Germany), Professor Dr. M^a Mercedes Carmona Martínez, and Professor Dr. M^a Vita Zhukova (both UCAM, Murcia, Spain), who scientifically supervised my doctoral thesis.

Special thanks to Professor Dr. Christian Soost (FOM University, Essen, Germany), who was a great help with his scientific insights from the field of empirical research.

Similarly, I extend my gratitude to all the survey respondents and expert interview participants for their invaluable contribution. This work would not have been achievable without your involvement.

Furthermore, I would like to express my gratitude to all those who have supported and accompanied me along the way.

III. QUOTE

*"Success is not the key to happiness. Happiness is the key to success.
If you love what you are doing, you will be successful."*

Albert Schweitzer

IV. ABSTRACT

In response to today's cost pressures, many companies are exploring strategies to reduce manufacturing expenses. One promising approach may be the establishment of a reliability engineering department (RED). However, there has been limited research on how REDs contribute to cost reduction and how they should be effectively integrated within an organization. This study explores the organizational and economic potential of REDs for manufacturing companies, investigating what businesses expect from creating their own REDs and how they evaluate the anticipated benefits, such as cost savings, minimized production losses, and increased equipment uptime. Additionally, the study considers the strategies employed to integrate a RED into the broader company structure and the factors beyond immediate cost analysis that influence the overall impact of such a department on a company's profitability.

To address this research gap, an exploratory qualitative expert survey was conducted. This qualitative study was preceded by a descriptive quantitative online survey as a preliminary study to access the scientific field. The findings reveal that many companies have already established or are planning to establish a RED. Organizationally, integrating the RED within the general maintenance department is the preferred approach. Companies primarily expect to achieve cost reductions in specific areas by implementing a RED, though the anticipated savings can vary. The study confirms that REDs can result in cost savings in the surveyed companies. Future research should focus on examining industry-specific factors and the challenges of implementation in small and medium-sized enterprises.

Keywords: Reliability Engineering, Maintenance, Organization, Qualitative Study, Costs, Key Performance Indicators

V. RESUMEN (SPANISH ABSTRACT)

En respuesta a las presiones actuales sobre los costes, muchas empresas están explorando estrategias para reducir los gastos de fabricación. Un enfoque promotor puede ser la creación de un departamento de ingeniería de fiabilidad (RED). Sin embargo, se ha investigado poco sobre cómo contribuyen los RED a la reducción de costes y cómo deben integrarse eficazmente en una organización. Este estudio explora el potencial organizativo y económico de los RED para las empresas manufactureras, investigando qué esperan las empresas de la creación de sus propios RED y cómo evalúan los beneficios previstos, como el ahorro de costes, la minimización de las pérdidas de producción y el aumento del tiempo de actividad de los equipos. Además, el estudio considera las estrategias empleadas para integrar un RED en la estructura más amplia de la empresa y los factores más allá del análisis inmediato de costes que influyen en el impacto global de un departamento de este tipo en la rentabilidad de una empresa.

Para abordar esta laguna en la investigación, se realizó una encuesta cualitativa exploratoria a expertos. Este estudio cualitativo fue precedido de una encuesta cuantitativa descriptiva en línea como estudio preliminar para acceder al campo científico. Los resultados revelan que muchas empresas ya han establecido o tienen previsto establecer una RED. Desde el punto de vista organizativo, la integración de la RED en el departamento de mantenimiento general es el enfoque preferido. Las empresas esperan principalmente conseguir reducciones de costes en áreas específicas mediante la implantación de una RED, aunque el ahorro previsto puede variar. El estudio confirma que las RED pueden generar ahorros de costes en las empresas encuestadas. Las investigaciones futuras deberían centrarse en examinar los factores específicos de cada sector y en los retos que plantea su implantación en las pequeñas y medianas empresas.

Palabras clave: Ingeniería de la fiabilidad, mantenimiento, organización, estudio cualitativo, costes, indicadores clave de rendimiento.

VI. TABLE OF CONTENTS

I. DIRECTORS AUTHORIZATION PAGE.....	5
II. ACKNOWLEDGMENTS	6
III. QUOTE	7
IV. ABSTRACT.....	8
V. RESUMEN (SPANISH ABSTRACT).....	9
VI. TABLE OF CONTENTS	10
VII. LIST OF ACRONYMS AND ABBREVIATIONS	15
VIII. LIST OF FIGURES.....	19
IX. LIST OF TABLES.....	22
1 INTRODUCTION	23
1.1 CONTEXT OF RESEARCH.....	23
1.2 OVERVIEW OF THE STATE OF RESEARCH.....	25
1.3 DEFINITION OF STUDY FOCUS AND BOUNDARIES	27
1.4 OBJECTIVE OF THESIS	32
1.5 METHODOLOGY	33
1.6 STRUCTURE OF THE THESIS.....	34
1.7 DEFINITION AND LIMITATIONS OF TERMS.....	35
2 THEORETICAL FOUNDATIONS AND STATE OF RESEARCH.....	39
2.1 THEORETICAL FOUNDATIONS.....	39
2.1.1 Relevant Theoretical Concepts of Business Administration in Strategy, Controlling and Organization.....	39
2.1.2 Reliability Engineering – Existing Definitions and Concepts ..	45
2.1.3 Maintenance – Existing Definitions, Functions, and Organisation	53
2.2 STATE OF RESEARCH	65
2.2.1 Approach to the Selection and Review of Studies.....	65

2.2.2	Results of the Study Review	69
2.2.3	Discussion of the State of Research.....	76
3	PRELIMINARY STUDY: CURRENT STATE ANALYSIS	83
3.1	DATA BASIS AND SAMPLING	83
3.2	TOOLS FOR PRELIMINARY STUDY	87
3.3	REALIZATION OF PRELIMINARY STUDY.....	90
3.3.1	Quality Criteria.....	90
3.3.2	Data Collection and Analysis	94
3.3.3	Determination of Questions for Preliminary Study.....	97
3.4	DETAILED FINDINGS.....	100
3.4.1	Section 1 – Basics and Overall Organization	100
3.4.2	Section 2 – Organization and Tasks of Reliability Engineering Departments	106
3.4.3	Section 3 – Budget of Reliability Engineering Departments.....	113
3.4.4	Section 4 – Expected Savings and Goals of Reliability Engineering Departments	115
3.5	FURTHER ANALYSIS OF THE FINDINGS	120
3.6	SUMMARY OF THE FINDINGS	129
3.7	REQUIREMENTS FOR THE MAIN STUDY.....	132
4	RESEARCH DESIGN	133
4.1	POTENTIAL RESEARCH METHODS.....	133
4.2	DETERMINATION OF RESEARCH METHOD FOR THE MAIN STUDY.....	147
4.3	RESEARCH GAP.....	149
4.4	DETAILED RESEARCH QUESTIONS.....	150
5	MAIN STUDY.....	153
5.1	DATA BASIS.....	153
5.1.1	Sampling.....	153
5.1.2	Sample Size and Theoretical Sampling.....	155
5.2	TOOLS FOR MAIN STUDY.....	159

5.2.1	Interview Guide and Consent Form	159
5.2.2	Questionnaire Creation.....	160
5.2.3	Pretesting	162
5.2.4	Technical Equipment.....	163
5.3	REALIZATION OF THE MAIN STUDY	163
5.3.1	Quality Criteria.....	163
5.3.2	Ethical and Legal Aspects of Interviewing Experts	165
5.3.3	Ensuring Ethical Standards and Privacy.....	166
5.3.4	Determination of Questions for Main Study.....	169
5.3.5	Consent Form and Interview Guide Application	174
5.3.6	Data Collection and Interview Setting.....	176
5.3.7	Conducting the Interviews	177
5.3.8	Theoretical Saturation	178
5.3.9	Transcription and Data Cleansing.....	181
5.3.10	Content Analysis and Coding.....	185
5.4	DETAILED FINDINGS.....	189
5.4.1	Section 1 – Basics/Organization.....	190
5.4.2	Section 2 – Reasons why Companies want to Implement a Reliability Engineering Department	194
5.4.3	Section 3 – Expected Savings through the Implementation of a Reliability Engineering Department	198
5.4.4	Section 4 – Evaluating the Effectiveness of a Reliability Engineering Department.....	203
5.4.5	Section 5 – Achievable Savings through a separate Reliability Engineering Department compared to a Conventional Setup	205
5.4.6	Section 6 – Concluding Remarks.....	206
5.5	RESEARCH QUESTION AND SUB-QUESTION FINDINGS	206
5.6	HYPOTHESES	215
6	DISCUSSIONS AND RESULTS	219
6.1	DISCUSSION	219
6.2	METHOD CRITICISM.....	223

6.3	IMPLICATIONS	224
6.4	RECOMMENDATIONS.....	225
6.5	FURTHER RESEARCH NEEDS.....	225
6.6	OUTLOOK	226
7	REFERENCES	229
8	APPENDICES.....	251
8.1	THE "10 COMMANDMENTS" OF QUESTION FORMULATION	251
8.2	EXEMPLARY SEARCH PROCEDURE LITERATURE ANALYSIS	252
8.3	QUESTIONNAIRE PRELIMINARY QUANTITATIVE ONLINE SURVEY	255
8.4	CODEBOOK QUANTITATIVE PRELIMINARY STUDY	264
8.5	INTERVIEW CONSENT FORM MAIN STUDY.....	267
8.6	INTERVIEW GUIDE MAIN STUDY	269
8.7	TRANSCRIPTED INTERVIEWS MAIN STUDY	271
8.7.1	Participant Information.....	271
8.7.2	Transcription Participant #1	272
8.7.3	Transcription Participant #2	275
8.7.4	Transcription Participant #3	280
8.7.5	Transcription Participant #4 (English Translation)	288
8.7.6	Transcription Participant #5	293
8.7.7	Transcription Participant #6	299
8.7.8	Transcription Participant #7	312
8.7.9	Transcription Participant #8	324
8.7.10	Transcription Participant #9	332
8.7.11	Transcription Participant #10	337
8.7.12	Transcription Participant #11	342
8.7.13	Transcription Participant #12	347
8.7.14	Transcription Participant #13	353
8.7.15	Transcription Participant #14	358
8.7.16	Transcription Participant #15	363

8.7.17	Transcription Participant #16	368

VII. LIST OF ACRONYMS AND ABBREVIATIONS

ADM	Arbeitskreis Deutscher Markt- und Sozialforschungsinstitute e.V. (i.e., Working Group German Market and Social Research Institutes e.V.)
AGREE	Advisory Group on Reliability of Electronic Equipment
AI	Artificial Intelligence
BDSG	Bundesdatenschutzgesetz (i.e., Federal Data Protection Act)
CAPEX	Capital Expenditures
CEN	European Committee for Standardization
Cf.	compare
CMMS	Computerized Maintenance Management System
CoPM	Cost of Poor Maintenance
COVID	Coronavirus Disease
DCS	Distributed Control System
DIN	Deutsches Institut für Normung (i.e., German Institute for Standardization)
EBSCO	an US-American database provider
EHC	Electro-Hydraulic Control
EHS	Environment, Health, and Safety (Department)
e.g.	exempli gratia (i.e., for example)
E&I	Electrical and Instrumentation
et al.	and others
etc.	et cetera (i.e., and so forth)
f	the following page
ff	the following pages
Fig.	Figure
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effects & Criticality Analysis

FOM	FOM Hochschule, Essen, Deutschland (i.e., FOM University, Essen, Germany)
FTA	Fault Tree Analysis
GDPR	General Data Protection Regulation
Hx	Hypothesis x
HROs	High-Reliability Organizations
IBM	International Business Machines Corporation (a US-American IT company)
ibid.	ibidem (i.e., to be found at the same place)
ICON	Independent Chlorination and Oxidation
i.e.	id est (i.e., that is)
IEEE	Institute of Electrical and Electronic Engineers
IRQ	Initial Research Question
ISO	International Organization for Standardization
ISQx	Initial Sub-question
IT	Information Technology
KI	Künstliche Intelligenz (i.e., Artificial Intelligence)
KPI	Key Performance Indicator
KPIs	Key Performance Indicators
MAXQDA	Computer program for analyzing research data
MCC	Motor Control Center
Mio.	million
MM	Mixed Methods
MS	Microsoft Corporation
MTBF	Mean Time between Failure
MTCE	Maintenance
MTTR	Mean Time to Repair
n/a	not applicable
OEE	Overall Equipment Effectiveness

OEM	Original Equipment Manufacturer
p.	page
PC	Personal Computer
PETG	Polyethylene Terephthalate Glycol-modified
PM	Preventive Maintenance
PSM	Process Safety Management
qual	qualitative study (not the main focus)
QUAL	qualitative study (main focus)
quan	quantitative study (not the main focus)
QUAN	quantitative study (main focus)
RAMS	Reliability, Availability, Maintainability, and Safety
RBM	Risk-Based Maintenance
RCA	Root Cause Analysis
RCM	Reliability-Centered Maintenance
R&D	Research & Development
RE	Reliability Engineering
RED	Reliability Engineering Department
SAE	US-American Society of Automotive Engineers
SAP	Software for Business Solutions
SLT	Site Leadership Team
SMEs	Small and Medium-sized Enterprises
spec	specification
SPSS	Statistical Product and Service Solutions (a computer program from IBM)
SRE	Site Reliability Engineering
t_{1-4}	time points for regular monitoring of the wear
t_a	time after exceeding the alarm threshold
t_f	failure time point
t_p	possible time for preventive maintenance action

Tab.	table
TiO ₂	Titanium dioxide
TPM	Total Productive Maintenance
UCAM	Universidad Católica San Antonio de Murcia, Spain
US	United States
USA	United States of America
VDI	Verein Deutscher Ingenieure (i.e., Association of German Engineers)

VIII. LIST OF FIGURES

Figure 1: Sequence of methodology	33
Figure 2: Porter's Five Forces Model (slightly simplified illustration) (Porter, 1979)	41
Figure 3: House of reliability (D. R. Kiran, 2017, p. 396)	47
Figure 4: Reliability engineering management support, simplified visualization (Calixto, 2013)	49
Figure 5: Approximate distribution of the effort between quality assurance and reliability (RAMS) engineering for complex equipment & systems with high quality and reliability (RAMS) requirements (Birolini, 2017, p. 17)	51
Figure 6: Main maintenance types, simplified illustration based on DIN EN 13306 (DIN Deutsches Institut für Normung e. V., 2018)	56
Figure 7: Preventive maintenance costs and corrective maintenance costs versus preventive maintenance effort (Ben-Daya et al., 2016, p. 13)	58
Figure 8: Concept of condition-based maintenance, slightly modified (Ben-Daya et al., 2016)	58
Figure 9: Components of operative maintenance management (Verein Deutscher Ingenieure, 2012, p. 28)	60
Figure 10: Subdivision of maintenance (DIN Deutsches Institut für Normung e. V., 2019, p. 12)	62
Figure 11: Functional organization as a staff-line system (Verein Deutscher Ingenieure, 2012, p. 12)	63
Figure 12: Matrix organization as a multi-line system (Verein Deutscher Ingenieure, 2012, p. 13)	64
Figure 13: Methods used in the studies investigated [%]	74
Figure 14: Sample size in studies investigated [%]	75
Figure 15: Research results [%]	76
Figure 16: Participating occupational groups [%]	101
Figure 17: Origin of participants by continent [%]	101
Figure 18: Employees at the site	102

Figure 19: Maintenance staff at the site.....	103
Figure 20: Own RED? [%]	105
Figure 21: Establishing a RED? [%]	106
Figure 22: Organizational allocation of the RED [%]	107
Figure 23: Reporting line of the RED [%]	108
Figure 24: General maintenance strategies (multiple answers possible) [%]	109
Figure 25: Realization of own reliability projects [%]	109
Figure 26: Organization purposeful? [%]	110
Figure 27: Does the RED deal exclusively with plant improvement? [%]..	111
Figure 28: Percentage of other activities [%]	112
Figure 29: Primary activities of the RED (multiple answers possible) [%]..	113
Figure 30: Own budget for improvement measures? [%]	114
Figure 31: Expected and achieved reduction in production losses [%].....	116
Figure 32: Expected and achieved reduction in maintenance budget [%]..	117
Figure 33: Expected and achieved extension of plant operating time [%]..	118
Figure 34: Expected savings in the future [%]	118
Figure 35: Used KPIs (multiple answers possible) [%]	119
Figure 36: Achievement of the RED targets [%]	120
Figure 37: Size of site and own saving projects	129
Figure 38: Decision choices for determining a mixed methods strategy of inquiry (Creswell, 2003)	143
Figure 39: Three basic mixed methods designs (Creswell, 2014, p. 220).....	144
Figure 40: Participating professions [%]	190
Figure 41: Concern with reliability engineering [%]	191
Figure 42: Reliability engineering types [%]	195
Figure 43: Reasons for a RED	197
Figure 44: Expected savings	199
Figure 45: Expected improvements	200
Figure 46: Quantified expected improvements through a RED	201

Figure 47: Used KPIs 204

IX. LIST OF TABLES

Table 1: Number of employees in the RED	104
Table 2: Maintenance budget spent on reliability measures.....	115
Table 3: Relation number of employees (all, maintenance, RED)	122
Table 4: Reporting line	123
Table 5: Maintenance strategy	125
Table 6: Maintenance strategy and savings.....	126
Table 7: Site size and savings	127
Table 8: Differentiating characteristics of surveys (Raithel, 2008, p. 66).....	135
Table 9: Classification of interviews according to their standardization, slightly modified (J. Gläser & Laudel, 2009)	137
Table 10: Participants of the study (anonymized). Please note that the participant number does not reflect the order of the interviews.	158
Table 11: Codes (final version)	187

1 INTRODUCTION

1.1 CONTEXT OF RESEARCH

For any manufacturing company, reliable and profitable machinery is of the utmost importance (S. Kiran et al., 2016). Failures, both major and minor, or even unexpected downtimes, are unacceptable and usually expensive in today's plants (Smith, 2011). This refers not only to the repair itself but also to the downtime, which is frequently far more expensive. A British study describes faulty machinery as the cause of three percent of lost production days (Williamson, 2017). Similarly, the company's reputation must be considered if it fails to meet an agreed-upon deadline. In order to keep the assets of a manufacturing company continually operational and in excellent running condition, companies of a certain size typically have their own maintenance organization. Maintenance can be performed by the company's internal staff or external contractors. These maintenance departments can vary in size (Knapp & Mahajan, 1998). Furthermore, they can also be organized differently. Various features and characteristics of an organization are feasible here. The goals of the individual departments are also quite different at times. For instance, in certain maintenance organizations, only failures are corrected, while others act preventively. Still, others focus on identifying failures before they arise (Strunz, 2012).

Efforts to enhance the reliability of a facility have typically fallen under the purview of the maintenance department (Madu, 2000). In certain larger corporations or sites, the responsibility for executing these initiatives rests with the asset management department, which oversees all assets within the company (Prüß & Diehl, 2009). Although it is often integrated into the maintenance department, the affiliation of this department may vary.

The reliability of facilities should increase constantly. Practical approaches and solutions are needed for real-world applications. One possibility would be to work more preventively (Jin, 2019). These solutions can be, for example, pre-planned maintenance actions or changing plant components before they come to the end of their life cycle. To further increase reliability, maintenance organizations have the opportunity to act more proactively. This means that these departments

identify potential failures before they occur and derive measures to prevent them from occurring in the future.

In some cases, this can substantially improve the equipment's reliability and save costs simultaneously (Eti et al., 2006). Independent departments concentrating solely on improving equipment reliability are formed mainly in medium-sized and larger companies. These usually develop out of the maintenance organization (Hawkins, 2015). Only a part of the tasks performed by these staff are the activities of a reliability engineering department (RED), as it is understood today.

In recent decades, to cut spending and enhance equipment reliability, more companies around the globe have established dedicated departments focused solely on asset reliability enhancement (Madu, 2005). At present, reliability engineering has become firmly established in larger companies, with the aerospace sector playing a pioneering role. The prevention of malfunctions is of crucial importance in this area. Due to the ever-increasing demands of the manufacturing sector, reliability engineering can now be found in many areas. (Moubray, 1997). Subsequently, a separate RED is an obligation for many companies. This development is quite a noteworthy milestone since setting up separate departments, primarily to increase the reliability of the equipment, is quite expensive. It is necessary to provide dedicated full-time personnel to identify and solve issues that have not yet occurred but may arise later. A RED can enhance the technical capabilities of machinery beyond what a standard maintenance organization can achieve (Calixto, 2013).

In this context, reliability engineering is a multidisciplinary field that focuses on managing a product or system throughout its lifecycle, from design and manufacturing to installation, maintenance, and repairs (Jin, 2019). Several defined processes, methods, and tools are applied to handle technical hazards (Dam, 2010). The specific tasks addressed by these REDs will depend on the individual company and may, therefore, differ distinctly from company to company.

Schmidt introduces a concept for the tasks and activities of a RED in "Reliability, Maintainability and Risk: Practical Methods for Engineers" (Smith, 2011). Various approaches for setting up a modern maintenance organization can be found in the specialist literature. In particular, the following stand out: "Organisation der Instandhaltung/Organisation of maintenance VDI 2895" (Verein Deutscher

Ingenieure, 2012) and Ben-Day, Kumar, and Murthy "Introduction to Maintenance Engineering: Modeling, Optimization and Management" (Ben-Daya et al., 2016).

A tangible impact on profits is crucial for all departments in a company. Therefore, the maintenance department and a RED must also play an essential role in this respect. The central question is how these departments must be organized and operate to improve a company's bottom line, whether through reducing maintenance costs, minimizing downtime, reducing production losses, or other measures.

These questions, which have so far not been considered in detail by the scientific community or only superficially, are the focus of this study. It aims to take a closer look at RED's organizational and operational aspects in manufacturing companies. This in-depth analysis is intended to close research gaps and contribute to further scientific discussion.

By looking at these two dimensions in more detail, this thesis also helps to develop a more comprehensive understanding of how a RED functions. This is important as REDs and their integration into an existing organization is often complex. By identifying research gaps and providing new insights, this thesis can help to better understand REDs and thus contribute to the further development of this field of research.

1.2 OVERVIEW OF THE STATE OF RESEARCH

Several studies addressed this work's issues or partial aspects, but often not in detail or with a different focus or objective.

Accordingly, Liao, Chen, and Yang describe an approach for "Joint optimization of preventive maintenance and production scheduling for parallel machines system." Using a mathematical model, they present a solution between production and maintenance schedules while minimizing the maximum completion time and total maintenance cost. The proposed method can substantially reduce the search space for solutions while avoiding the trap of "detail optimization." The model needs to be verified in an actual manufacturing process. It is an exciting approach that combines all relevant factors (Liao et al., 2017).

Chen and Bao describe how to improve reliability based on the reliability of individual system components through cost-reliability analysis and a way to

identify the importance of various system components. They note that different measures to increase component reliability can affect system reliability and different types of costs. The techniques must be applied to actual cases to test their effectiveness in practice. This publication is a mathematical representation of the question. Practical testing is still pending (Chen & Bao, 2013).

Kareem, Saeed, and Faraj investigated the role of maintenance practices in poor uptime of operating equipment in the context of business dynamics in industrial companies. For this purpose, they surveyed maintenance practices in industrial enterprises. The result shows that organizations' reliance on the practice of inspections and verifying equipment status can greatly limit breakdowns. The data was collected exclusively from companies in the Kurdish part of Iraq. It is unclear whether the results can be generalized to the Western world. This work is, however, a well-designed study of maintenance practices (Kareem et al., 2019).

Rosqvist, Laakso, and Reunanen described how to specify functional requirements for the equipment locations and equipment. They have to identify appropriate objects and tasks for preventive maintenance. The authors proposed a model and conducted a case study. As a result, they describe the optimal allocation of maintenance resources among equipment with varying risks, given a preventive maintenance budget limit. So far, the model has been tested only on one company in a case study. However, the approach seems too complex to apply to a whole company (Rosqvist et al., 2009).

Aven carried out a literature review and used mathematical models to clarify concepts and further develop principles, methods, and models for understanding reliability and determining the "right" level of reliability. Further research and development in reliability engineering are essential to address the challenges of the future. No expert first-hand experience has been contributed, and no real-world tests have been performed (Aven, 2017).

Detailed models of maintenance organization related to a RED are not discussed in the accessible literature. Likewise, no information on actual cost savings through a RED is available.

1.3 DEFINITION OF STUDY FOCUS AND BOUNDARIES

Research Gap

The evaluation of the relevant studies conducted within the framework of this research work has revealed a series of apparent trends and limitations that offer valuable insights into the state of knowledge in the maintenance and reliability engineering domain. These patterns underscore certain vital aspects that warrant further investigation and attention:

Firstly, a prevalent theme in several studies is the perception of maintenance primarily as a reactive department (Hodapp, 2018; Salonen & Deleryd, 2011). This viewpoint characterizes maintenance as a responsive unit that addresses issues as they arise, often in a firefighting manner. In contrast, some studies and standard maintenance manuals recognize the importance of preventive maintenance, emphasizing the value of proactive measures to forestall breakdowns and inefficiencies (Hasanah & Wulandari, 2019; Strunz, 2012). Interestingly, predictive maintenance, a strategy that uses data and analytics to predict equipment failures and plan interventions, is often overlooked in discussions. This suggests a potential underutilization of predictive maintenance practices in the industry despite its potential to enhance operational efficiency and reduce downtime.

Secondly, organizational maintenance dimensions receive limited attention and elaboration across the reviewed studies. While maintenance is undeniably a technical function, it also has substantial organizational implications (Verein Deutscher Ingenieure, 2012). These include resource allocation, the creation of efficient processes, and the implementation of strong management practices. The lack of focus on these organizational facets within the literature signifies a gap in understanding how maintenance should be structured within the broader context of an organization.

Thirdly, some studies and maintenance manuals touch upon the concept of reliability engineering (Aven, 2017; Birolini, 2017). However, they often fail to provide concrete recommendations or insights into how reliability engineering can be effectively integrated into existing maintenance practices or, more ambitiously, the entire organizational framework. The absence of practical guidance implies that organizations may struggle to implement reliability engineering principles effectively.

Fourthly, the core responsibilities and tasks of a RED, a critical component in reliability-focused organizations, are rarely mentioned or briefly alluded to. The available literature in the field of reliability engineering often refers exclusively to mathematical models (Elsayed, 2021; Jin, 2019). This lack of clarity regarding the specific roles and functions of a RED calls for further investigation to establish a comprehensive understanding of its role within an organization.

Fifthly, the reviewed studies do not address the potential savings and benefits associated with implementing a RED. The economic advantages of investing in reliability engineering are essential for justifying its incorporation into an organization's operational strategy.

Furthermore, the evidence of anticipated savings compared to realized savings is scarcely explored in the literature. This absence of concrete data makes it challenging to assess the genuine impact achieved through adopting reliability engineering practices.

In addition, there is a notable lack of information regarding key performance indicators (KPIs) specific to reliability engineering. Establishing relevant KPIs is crucial for assessing the effectiveness and performance of reliability engineering initiatives (Marr, 2012). Their absence raises questions about how organizations evaluate the success of their reliability engineering programs.

Finally, a common characteristic of most of the reviewed studies is their reliance on literature-based research or theoretical mathematical models (Erbe et al., 2007; Maji et al., 2020; Navas et al., 2020). This predominant trend suggests that much of the existing knowledge in this field is derived from theoretical frameworks and lacks substantial empirical validation. The limited use of empirical data suggests a need for more real-world research and practical experimentation to validate and refine the theoretical concepts underpinning maintenance and reliability engineering.

In summary, evaluating existing studies in this research work highlights several noteworthy trends and gaps in the maintenance and reliability engineering domain. These patterns suggest ample room for further research to enhance our understanding of how organizations can effectively integrate reliability engineering practices and realize their full potential. Additionally, a shift towards empirical research, the establishment of clear KPIs, and a more comprehensive examination of

the organizational aspects of maintenance could provide more tangible insights into the impact of reliability engineering on operational efficiency within organizations.

Scope and Delimitation of the Research Field

This thesis explores research gaps in the field of reliability engineering. Due to the many existing gaps, defining a certain scope and boundaries for the work is necessary to ensure a manageable and focused approach.

The main concern is on reliability engineering departments' key operational and organizational components in manufacturing companies, focusing on performance improvements. This scope includes outlining the outcomes and benefits organizations can achieve by establishing a reliability engineering department. In particular, the corresponding costs and possible savings are considered vital aspects. It also looks at the methods and criteria companies use to evaluate the effectiveness of their RED. It likewise examines the organizational strategies and practices used to successfully integrate a separate RED into the overall corporate structure.

Finally, factors and considerations that go beyond the immediate cost aspects will be taken into account. It examines how these factors can influence the perceived impact of establishing a separate RED on an organization's profitability. The comprehensive analysis of these aspects will help to develop a deeper understanding of the importance of reliability engineering in organizations and will provide sound recommendations for the effective implementation and evaluation of such departments.

Delimitations refer to the boundaries a researcher sets, encompassing what is incorporated and excluded to ensure a project remains manageable and concentrated on the core research question (Coker, 2022). Theofanidis and Fountouki explain that any research is inevitably confronted with limitations and delimitations that can affect various aspects. Researchers should be aware of these limitations at an early stage, critically question their assumptions, and transparently point out shortcomings. It is important to actively address these aspects in the research process (Theofanidis & Fountouki, 2018).

In this work, it is necessary to make clear delimitations. The study is not limited to a single country, reflecting the increasingly interconnected nature of the global landscape. Its main aim is to include international managers and locations in the study. To this end, expert interviews are conducted with people based in different countries within Europe.

In particular, the focus is on maintenance departments with separate REDs, which typically have characteristics of larger companies or larger locations, especially those with more than 250 employees. In contrast, small and medium-sized enterprises (SMEs) usually do not have such dedicated departments in their organizational structures. Therefore, the expert interviews focus on larger companies as defined by Eurostat (European Commission – Eurostat, 2021).

The thesis pursues a comprehensive approach and aims to include as many different industries as possible. However, REDs are particularly widespread in the chemical industry. This sector is, therefore, strongly, but not exclusively, represented in the expert interviews.

The global coronavirus pandemic posed a particular challenge for this study. Face-to-face interviews, a standard data collection method, were impossible due to health and safety concerns. The study, therefore, had to resort to video conferencing as an alternative interview method. This adaptation was necessary to ensure the safety of both the study participants and the researcher while maintaining the continuity and effectiveness of the data collection.

Initial Research Question

Research questions are crucial to the research process, as they provide essential guidance and direction for the investigation. At their core, research questions compel researchers to think about the most foundational aspect of any research undertaking: what they genuinely want to understand or uncover. These questions direct the research, helping researchers define their study's scope, purpose, and objectives (Bell et al., 2019).

Alongside the main research question, several sub-questions are introduced. These questions refine the scope of the study concerning the primary research question (Creswell & Creswell, 2018). Creswell and Creswell recommend limiting the

number of subsidiary questions related to the main question to no more than five to seven (ibid.).

Given the complexity of the research question, this study breaks it down into smaller, manageable components to enhance clarity and analysis. This approach is essential as it refines the research focus and provides a more precise direction. These sub-questions are more specific and aim to shed light on different aspects of the overall topic for deeper analysis and focused investigation.

The initial research question and initial sub-questions are reviewed during the research process. Adjusting and clarifying the initial research question and initial sub-questions may be necessary as the research progresses. This may be for various reasons, such as the discovery of new knowledge, the emergence of unexpected questions, or the refinement of the research methodology. The final research question with its formulated sub-questions is presented in Chapter 4 - Research Design.

Initial Research Question and Initial Sub-questions

The main research question is about understanding the key operational and organizational elements within reliability engineering departments in manufacturing companies. The sub-questions will address specific aspects such as the expected outcomes that companies seek when establishing such departments, the expectations and performance indicators associated with the contributions of reliability engineering, the methods used to evaluate effectiveness, the organizational strategies for integration, and the broader factors that influence the perceived impact on a company's profitability beyond the immediate cost analysis.

Subsequently, the following initial research question (IRQ) and initial sub-questions (ISQx) are defined:

IRQ: What operational and organizational elements for reliability engineering departments apply to improve a company's performance in the manufacturing industry?

ISQ1: What drives companies to set up reliability engineering departments?

ISQ2: What concrete savings in the area of key performance indicators (KPIs) do companies expect from a reliability engineering department?

ISQ3: How are these savings measured?

ISQ4: What organizational structure do companies with REDs have?

ISQ5: Can a RED increase the company's earnings?

1.4 OBJECTIVE OF THESIS

The primary goal of this study is to address existing research gaps and deepen the understanding of key aspects related to reliability engineering departments (REDs), both within maintenance departments and the broader organizational structure of companies. To contribute to the scientific discourse, this research examines aspects that have not yet been explored or documented in the relevant literature. The study intends to shed light on several dimensions, including the potential savings and benefits realized through the implementation of REDs, the structural components that define their existence, the specific functions and tasks they perform, and the overall organization and integration of REDs within manufacturing companies.

The objective of this research is to formulate an operational and organizational framework that can serve as a valuable guide for manufacturing companies seeking to improve their performance through the implementation of a RED. This framework will not only include the structural and functional aspects but will also be complemented by insights into the expectations of companies regarding REDs. In addition, the study will outline the potential benefits that a RED can bring, helping companies to justify their investment in reliability engineering.

Another critical aspect of this study is the approach that organizations use to evaluate the effectiveness and efficiency of their REDs. Understanding how organizations measure the performance and impact of REDs is vital to ensuring that these departments are aligned with overall organizational goals and contribute to overall success.

Finally, this study seeks to determine whether the presence and effectiveness of a RED can lead to increased profitability for an organization.

1.5 METHODOLOGY

This research employs a complex approach, encompassing various methods across different phases to comprehensively address this dissertation's subject matter. The sequence is shown in abbreviated form in Figure 1.

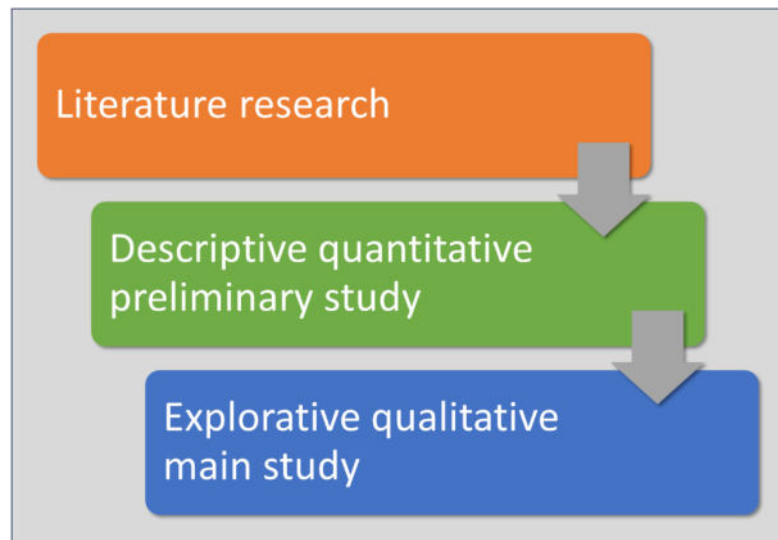


Figure 1: Sequence of methodology

The initial phase involves a rigorous and systematic examination of literature relevant to the dissertation topic. This literature review is characterized by its focus on scholarly studies and relevant expert publications, providing a solid foundation for the subsequent stages of the research.

Following this literature review, a descriptive quantitative preliminary study is conducted to assess the field's current state, serving as a preparatory step for the primary research endeavor. A preliminary study is essential in this context, as the to-date research in this scientific field is extremely limited. The questions for the qualitative main study will also be derived from this quantitative preliminary study.

The core of this research effort revolves around an explanatory qualitative survey conducted in the form of expert interviews. The main qualitative study will provide key, in-depth insights into this particular scientific field. Qualitative studies formulate meaningful general statements as hypotheses, even though they

cannot be universally generalized. These hypotheses should be tested for accuracy in subsequent studies (Mayring, 2007).

The involved participants in these interviews include senior personnel with expertise in maintenance and reliability and individuals holding roles as plant and site managers. This selection ensures the creation of a robust and comprehensive database that can effectively inform the research.

Subsequently, the gathered data undergoes a thorough and comprehensive evaluation and analysis to extract meaningful insights and draw conclusions. This analytical phase is instrumental in uncovering patterns, trends, and valuable information that can address the research questions and objectives.

The final phase of this research is dedicated to documenting the findings derived from the data analysis. This documentation summarizes the research outcomes, providing clear and insightful answers to the research question and its sub-questions that guided the entire study. This research methodology involves a sequential progression to facilitate a holistic and systematic exploration of the subject matter of the dissertation.

This methodical approach enables data to be collected for the first time in the field of reliability engineering, which was previously unavailable from a scientific perspective. This makes it possible to identify and close knowledge gaps in this specific area of maintenance in manufacturing companies.

1.6 STRUCTURE OF THE THESIS

This dissertation is clearly structured and follows a straightforward organization. In the first chapter, the summarizing introduction provides an overview of the research topic. It opens with a description of the research context, followed by an overview of the current state of research. This chapter includes the definition of the study focus and boundaries, which describes the research gap, the scope and the delimitation of the research field, as well as the formulation of the initial research question with its sub-questions. It concludes with the objective of the thesis, the methodology, the structure of the thesis, and the necessary definitions and limitations of terms. The second chapter is dedicated to the theoretical foundations and the state of research. Here, condensed relevant theories and terms are explained for a better understanding, and the current state of research on the topic is

presented. This includes an explanation of the selection and review of studies, a detailed presentation of the results of the study review, and a discussion of the state of research, including the identification of gaps, which are also provided in this chapter. The third chapter deals with the descriptive quantitative preliminary study, including the data basis and sampling, the tools used, the actual realization of the preliminary study as well as the detailed findings. The fourth chapter is concerned with the research design for the main study. Here, different possible research methods are outlined, the rationale for the chosen methodology of the main study is presented, and the identification of the research gaps and the final research question with the corresponding sub-questions are provided. The fifth chapter gives an insight into the data basis, the tools, the realization, and the detailed findings of the explorative qualitative main study. New hypotheses are also presented. The sixth chapter contains the discussion and the presentation of the results. Method criticism, implications, recommendations, and the need for further research are discussed here.

The seventh chapter contains the references used, while the eighth chapter concludes with the appendices.

1.7 DEFINITION AND LIMITATIONS OF TERMS

The varying definitions of terms in the academic literature are challenging. The meanings of words and concepts may vary slightly or even considerably, depending on the specific context and field of application. This terminological diversity introduces the potential for ambiguity, underscoring the importance of offering precise definitions within the framework of this research. This sup-chapter establishes the definitions of terms pertaining to this thesis. Further elaboration on the various terms will be provided for a better understanding in the subsequent chapter (Chapter 2 - Theoretical Foundations and State of Research) if required.

Reliability

When the term "*reliability*" is defined, the focus is often on the reliability of the product. Nevertheless, this is only a fraction of a wide range. Just as decisive for a company's performance is the reliability of the manufacturing equipment used to produce the product in question. Blischke and Murthy provide a definition

of reliability, stating that it is the likelihood of a product or system successfully carrying out its intended function within a designated timeframe while operating under typical environmental conditions. This concept emphasizes the probability of sustained performance under normal or specified circumstances (Blischke & Murthy, 2000).

Reliability management addresses the diverse managerial concerns associated with the design, manufacture, and/or operation and maintenance of dependable products and systems (Blischke & Murthy, 2003). It can be described even more simply as the management of reliability engineering (Calixto, 2013).

Furthermore, *reliability engineering* is a multidisciplinary field that encompasses the lifecycle management of a product or system, spanning from design and manufacturing to installation, maintenance, and repair services (Jin, 2019).

Dam offers a broader perspective, defining reliability engineering as the application of well-defined engineering processes, methodologies, and tools to identify, understand, and manage technical risks (Dam, 2010).

Often, reliability engineering is used synonymously with *software reliability engineering*, which is defined as engineering techniques for developing and maintaining software systems (Lyu, 2007).

Site reliability engineering (SRE) is not precisely defined. However, the activities in this area relate exclusively to the field of software or computer networks. The focus is on improving, designing, and operating computer systems, considerably increasing dependability and efficiency. The term "site" here refers to "website" (Sloss, 2016).

The term "*high-reliability organizations*" (*HROs*) dates back to 1986 when researchers noted similar characteristics in organizations that appeared to operate error-free despite their high error-proneness and complexity (Cantu et al., 2021). The three high-reliability organizations were the Federal Aviation Administration's air traffic control system, a Pacific Gas and Electric Company nuclear power plant, and a US Navy nuclear aircraft carrier (ibid.).

In the context of this study, the term "reliability" always refers to the reliability of production plants or production machines. A narrowly defined exception arises in this regard. The sub-chapters 3.3.1 and 5.3.1 describe the quality criteria of quantitative and qualitative surveys. In this context, the criterion of "reliability" is

described, among other criteria. This term is also named in the specialized literature. Thus, a descriptive renaming of this criterion was out of the question. Therefore, this term is used exclusively in this chapter for another meaning.

Networks and software are entirely excluded from the discussion. Furthermore, the term "high-reliability organization" describes a specific area that is associated with several assumptions and limitations. Throughout the study, however, this term remains excluded with all its limitations.

Maintenance

A specific standard in the European Union is the DIN EN 13306:2018-02, issued by the European Committee for Standardization (CEN) and published in Germany by the DIN – Deutsches Institut für Normung e. V (i.e., German Institute for Standardization) (DIN Deutsches Institut für Normung e. V., 2018) defines how the term "*maintenance*" should be understood. This standard outlines the concept of maintenance as a comprehensive set of actions carried out throughout the life cycle of an object. These actions aim to sustain the object's condition or restore it to a condition where it can effectively perform its intended function. This maintenance concept includes activities such as observation, analysis, and actual maintenance actions, such as DIN explained (ibid.).

Maintenance management encompasses all management activities to establish and implement maintenance requirements, objectives, concepts, and responsibilities in an organization. It includes tasks such as maintenance planning, control, and increasing maintenance efficiency, all of which contribute to the effective management of maintenance needs, as articulated in the DIN EN 13306:2018-02 standard (DIN Deutsches Institut für Normung e. V., 2018).

Recognizing that the maintenance field is complex and can interact with other areas, such as software or network maintenance, is vital. In this research context, the term "maintenance" primarily refers to technical maintenance, in particular, the maintenance of equipment according to DIN EN 13306:2018-02.

Asset Management

The sole term "*asset*" is relevant in several areas, but its definition can vary depending on context. In a 2019 publication, Lange describes the term "asset" as a

catch-all term for resources companies acquire to achieve specific business goals, including factors such as return on investment, safety, and liquidity (Lange, 2019). However, there is no universally accepted definition for the term "*asset management*" in the literature, which can lead to confusion. In fact, the term is sometimes mistakenly equated with "*maintenance management*" or even written in different forms, such as "*asset management*" or "*asset administration*."

A 2015 study by Alfatih, Leong, and Hee underscores the diversity of perspectives on asset management, emphasizing that it is a broad and multifaceted field defined differently by different experts (Alfatih et al., 2015). To clarify, CEN offers a concise definition in DIN EN 16646:2014, which states that asset management comprises a coordinated set of activities within an organization aimed at creating value by managing its assets (DIN Deutsches Institut für Normung e. V., 2015).

However, Gläser, in his publication "Media Management," takes a different view and defines asset management as the administration of legally relevant content as part of content management (M. Gläser, 2014). On the other hand, Lange sees the central purpose of asset management as monitoring an investment portfolio from a risk and return perspective, often provided as a service by financial intermediaries (Lange, 2019). Another asset management interpretation is in Arcuri's work "Asset Management: Strategies, Opportunities and Challenges." Arcuri defines it as the selection and long-term management of various financial instruments, both listed and unlisted, intending to achieve the best possible return at an acceptable level of risk (Arcuri, 2019).

A more focused form of asset management is *engineering asset management*. It focuses exclusively on physical assets such as equipment, buildings, and inventories (Alfatih et al., 2015). Although engineering assets have a financial dimension, another publication describes the term "engineering asset management" as being used to differentiate it from financial asset management (Amadi-Echendu et al., 2010).

Plant asset management, a specialized subfield, focuses on engineering assets directly involved in production. The definition serves to distinguish it from the financial sector. In the process industry, the term "plant asset management" is predominantly used to describe its asset management (Brumby, 2018).

In the context of this thesis, the term "asset management" refers primarily to the area of technical asset management, specifically plant asset management. It is important to note that this does not include financial asset management, a separate and distinct discipline.

2 THEORETICAL FOUNDATIONS AND STATE OF RESEARCH

This chapter provides a condensed overview of the key concepts and definitions central to the topic. This approach is intended to provide a solid foundation for understanding the broader field and does not claim to be an exhaustive list. These basic terms are the cornerstones upon which the following research is built. The goal is to avoid ambiguity. In addition, the existing literature on the topic is outlined. The literature sources also made it possible to position the present study in the context of research. Illustrations have been used where they have been deemed helpful for a better understanding. This does not imply a weighting of the importance of the respective topics.

2.1 THEORETICAL FOUNDATIONS

2.1.1 Relevant Theoretical Concepts of Business Administration in Strategy, Controlling and Organization

The area of business administration is broad and diverse. This overview will briefly describe the areas of strategy, controlling and organization that are particularly relevant to this thesis.

The term "strategy" in business administration has many meanings, and managers interpret it differently. Many believe they are competent in strategy development and implementation, and management consultancies offer strategy services. However, there is no firm consensus on the content, development, and implementation of strategy (Wicharz, 2018). Dietrich and Meitinger explain that a corporate strategy is a long-term framework that is aligned with a company's goals and business plan and aims to ensure its economic success (Dietrich & Meitinger, 2021).

According to Wicharz, strategies consist of four components: mission, vision, transformation program, and success logic. The mission defines the company's intended benefits to its primary stakeholders and answers the question of what value the company wants to provide to its stakeholders. The vision outlines the company's desired image and how it intends to position itself in the marketplace. The transformation program describes the roadmap for change, detailing the steps needed to achieve the vision. The success logic covers industry principles and addresses how different business models and structures affect the company's ability to deliver value in a changing environment (Wicharz, 2018).

There are various proposals for developing business strategies, including Michael Porter's five forces model. More recent approaches focus on adapting to changes in the business environment. Strategy formulation involves defining the purpose and scope of business activities, taking into account the environment, market positioning, and competition. Business planning then implements the strategy (Dietrich & Meitinger, 2021).

Understanding the current market is critical to effective long-term strategy alignment. Michael E. Porter's Five Forces Model provides a framework for analyzing industry attractiveness and competition by focusing on five key factors (illustrated in Figure 2): Competitive rivalry is influenced by the number of competitors in the market, the growth of the industry, and the degree of product differentiation. The threat of new entrants depends on barriers to entry, such as economies of scale, which can prevent new competitors from entering the industry. The bargaining power of suppliers affects prices, especially when switching costs are high, while the bargaining power of customers affects prices and quality demands, which may also be affected by switching costs. In addition, the threat of substitution arises from alternative products that perform similar functions, especially when customer loyalty to existing products is low. Governments also influence industry structure, although Porter does not explicitly include them as a separate force (Porter, 1979).

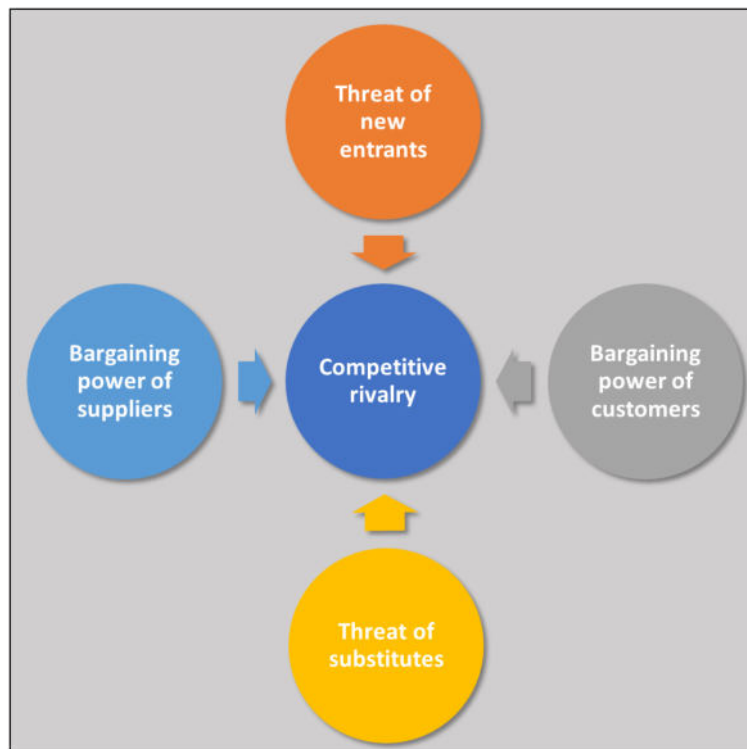


Figure 2: Porter's Five Forces Model (slightly simplified illustration) (Porter, 1979)

Porter's model provides a comprehensive view of competition and identifies opportunities and risks, but it has been criticized for assuming a static market structure and not considering modern market dynamics or strategic alliances. Despite its limitations, it provides a starting point for strategic thinking.

There is no single, perfect path to the right business strategy. As Körndörfer pointed out in 1990, the initial enthusiasm for strategic planning as a revolutionary tool gave way to a more realistic view. While exaggerated expectations have led to disappointment, strategic planning remains vital when integrated with a comprehensive approach. Clear objectives must be derived from the corporate mission, and strategic business units should be well-defined. Portfolio analysis should be flexible, and close cooperation between planning staff and line managers is essential in large companies, with strategy development primarily in the hands of the line (Körndörfer, 1990). Integrating strategic planning, organization, and monitoring is critical to avoid failure. Future strategic planning should consider the importance of key technologies and focus on developing innovative product-market-technology combinations. Creative approaches to entering new markets will

increasingly replace quantitative thinking about market share and growth. Strategic thinking should be embedded in the corporate culture at all levels (ibid.).

In summary, strategy in business administration is complex, with different interpretations among managers and no consensus on its content or implementation. Strategies include mission, vision, transformation program, and success logic. Frameworks such as Porter's Five Forces help analyze industry structure but are criticized for their static nature, underscoring the need to align with business goals and foster innovation within organizational culture.

Much like the concept of strategy, business management literature has no uniform definition of controlling. Generally, controlling involves coordinating a company's planning, analysis, control, and information supply. It may also include organization and personnel management (Buchholz, 2019). Distinguishing between controlling, internal auditing, and treasuring is essential. Controlling accompanies the control cycle process, while internal auditing focuses on retrospective monitoring. Conversely, treasuring deals with finance-oriented activities like capital procurement and managing investor relations (Fiedler & Gräf, 2012).

Hering defines controlling as encompassing steering, managing, and controlling. It systematically controls objectives with measurable target values, comparing actual with planned values to analyze deviations. Decisions are made to initiate corrective measures to optimize target achievement. The goal of controlling is to use resources effectively to meet company goals swiftly (Hering, 2014). The importance of controlling varies depending on the corporate culture and financial situation. It plays a vital role in financially challenging situations and acts as a business partner in companies with a balanced power distribution between departments (Behringer, 2018). Controlling is divided into strategic and operational types. Strategic controlling analyzes trends, strengths, and weaknesses, develops opportunities and risks, and adjusts strategies. Operational controlling ensures liquidity, profitability, and efficiency by analyzing deviations between planned and actual results and taking corrective actions (Hering, 2014).

Strategic and operational controlling runs throughout the entire organization, encompassing various functional areas such as procurement, production, marketing, and human resources. Each area requires strategic and operational

control to optimize performance and achieve goals (*ibid.*). Controlling tasks can be grouped into four areas: planning, monitoring results, reporting, and accounting. Planning involves developing and coordinating business plans. Monitoring involves comparing targets with actual results, controlling processes, and safeguarding assets. Reporting includes the development of management information systems and external reporting. Accounting deals with legal compliance, decision support, and tax issues (Korndörfer, 1990).

Generally stated, controlling in business administration involves coordination, planning, analysis, and information provision. It is divided into strategic and operational aspects, with functions such as planning, monitoring, reporting, and accounting, all aimed at optimizing performance and achieving business goals. Controlling is critical in financially challenging situations and requires direct reporting to management for effective action.

Business organization encompasses a variety of models for governing business tasks, responsibilities, and communication channels. Organizational structure determines how tasks, authority, and responsibilities are distributed within an organization. It involves the creation of organizational units and the definition of instruction and information paths, typically visualized in an organizational chart (Spath, 2017). Dynamic environments and market changes force companies to adapt quickly, which affects organizational structures and employee competencies (Buck, 2017). A poorly designed structure can negatively affect work processes, as outdated frameworks may result in suboptimal performance (Marek, 2020). Process organization focuses on coordinating the sequence and flow of tasks and materials and optimizing workstations and timings for business transactions. In contrast, structural organization defines tasks, competencies, and responsibilities, establishing organizational units and information flows. This structural framework is typically depicted in an organizational chart (Spath, 2017).

Effective organizational design aims to balance workload distribution and overall performance. Differentiation (dividing tasks) and integration (combining efforts) are key concepts, as task division requires coordination among employees (Marek, 2020).

Organizational hierarchical structures vary in their approach to authority and management. In a single-line organization, each employee reports to a single direct supervisor, which ensures clear lines of authority but can result in a high communication burden due to long chains of command. Alternatively, a multi-line organization distributes management responsibilities among several specialized entities, resulting in employees reporting to multiple managers. This model often faces challenges with diluted authority, although the matrix organization is a common variation that addresses some of these issues. Another structure, the staff line organization, builds on the single-line model by incorporating staff units that provide specialized support. These staff units typically have minimal decision-making authority and are designed to either support specific instances or serve the entire company, relieving or centralizing various services as needed (Lippold, 2016). Variations and hybrid forms are also possible (Marek, 2020). Graphic examples of some organizational forms in the context of maintenance organization are shown in section 2.1.3 (Maintenance - Existing Definitions, Functions, and Organisation). The line management system regulates subordination and superordination. The functional organizational model, in which top management is divided into functional areas such as sales or production, was historically dominant and remains common in smaller companies (Daum et al., 2010). In divisional organizations, business units are often structured around products, customers, or regions. For example, a vehicle manufacturer may have divisions for commercial vehicles, passenger cars, and bicycles. However, such divisions can be inefficient because they duplicate functions that could be centralized for greater efficiency (ibid.).

Whole organizations can also adopt alternative structures such as networks, clusters, or alliances (Bußmann et al., 2013). As organizations expand, managers must regulate and synchronize activities critical to value creation, focusing on balancing differentiation and coordination to achieve goals (Jones, 2013).

In conclusion, business organization involves various models and structures to effectively manage tasks, responsibilities, and communication channels. The key challenge is to balance workload distribution and coordination, using appropriate hierarchical structures to optimize performance and adaptability.

2.1.2 Reliability Engineering – Existing Definitions and Concepts

Kapur and Pecht note that there is a consensus that reliability is an important characteristic of a product, although there is no general definition of reliability. In dictionaries, reliability (noun) is specified as the state of being reliable, and reliable (adjective) is specified as something that can be relied upon or is dependable (Kapur & Pecht, 2014). As described in the previous chapter, when discussing the concept of "reliability," the focus is often placed on the reliability of the product. However, this is only one part of a broader spectrum. Equally critical to a company's effectiveness is the reliability of the production equipment used to manufacture the product in question. While quality and reliability are often seen as interchangeable (Braglia et al., 2007), it is important to recognize that reliability should be understood as the enduring quality of a product, system, site, etc. over a period of time (ibid.). Blischke and Murthy define reliability as the probability of a product or system effectively performing its intended function within a specified timeframe and under typical environmental conditions. This concept underscores the likelihood of consistent performance in regular or specified situations (Blischke & Murthy, 2000).

The term "reliability engineering" also encounters a comparable situation, as diverse descriptions are present in specialized literature. Jin specifies that reliability engineering is a multidisciplinary area that deals with the life cycle management of a product or system. The area covers design, manufacturing, installation, maintenance, and repair services. To ensure the safety of people, reliability is vital, as is the cost-efficiency and stable operation of infrastructure and systems. Reliability engineering has become a critical factor in both the private and public sectors. As a key performance measure, this includes manufacturing, healthcare, transportation, energy, chemical and oil refining, aerospace, and defense industries (Jin, 2019). Blischke and Murthy state that reliability engineering is concerned with designing and constructing systems and products. Here, the unreliability of their parts and components must be considered. An integral part is reliability improvement testing and programs. Good engineering leads to a more reliable end product (Blischke & Murthy, 2003). According to Dam, reliability engineering involves employing well-defined engineering processes, methodologies, and tools to identify, understand, and manage technical risks, providing a comprehensive outlook (Dam, 2010). Kiran explains that reliability engineering is an engineering framework that enables the

definition of a complete production system. In order to fulfill the required functions under specified conditions over a specified period, reliability engineering deals with the study of a product's capabilities. It defines measures and analyzes the failure and repair of systems. The goal is to extend the service lifespan, minimize failure risks, and lower the likelihood of breakdowns. (D. R. Kiran, 2017).

Historically, proper reliability engineering began quite early. The beginning of the electronic age led to the need for more complex, mass-produced components with a higher degree of variability in parameters and dimensions. Poor reliability experiences with military equipment in the 1940s and 1950s, in particular, reinforced the need for formal reliability engineering methods. To this end, more failure data were collected from the field and evaluated (Smith, 2011).

Nakagawa states that the reliability theory emerged from the valuable experience of many defects in military systems during World War II and the concomitant development of modern technology (Nakagawa, 2005). A US study group was started in 1950 to deal with this topic systematically. This group was named the Advisory Group on Reliability of Electronic Equipment (AGREE). The first report was published in 1952. For the creation of reliable systems, it stated that, first, there was a need to develop better components and ensure more consistency among suppliers. Second, the military should establish quality and reliability requirements for suppliers. Third, actual field data on components should be collected to determine the causes of problems (Tan, 2017).

In 1960, the first postgraduate school in Monterey, California, USA, began teaching reliability engineering (Kececioglu, 2002). Subsequently, the Society of Reliability Engineers was founded in 1966 in the USA (Buffalo/New York) (ibid.). In 1978, the Institute of Electrical and Electronic Engineers (IEEE) founded the IEEE Reliability Society (ibid.).

Starting in the 1980s, high-speed digital computers with stored programs were widely available. As performance increased, IT became a practical tool for engineers. Simulating was possible thanks to a high-speed computer. With more sophisticated tools, such as IT, engineers became more specialized from the 1980s onward than before. Reliability engineering emerged as one of these more specialized directions, along with others (Tamanacharya, 1998).

Beginning in the post-1990 era, the acronym RAMS stands for reliability, availability, maintainability, and safety. The term "reliability engineering" is also used for "RAMS engineering" (Biolini, 2017). Finally, a series of European reliability standards began to be developed in the 1990s. These were successively integrated into the International Standards Organization (ISO) (O'Connor & Kleyner, 2012). The US-American Society of Automotive Engineers (SAE) issued the standard JA1011 "Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes" in 1999 (Siddiqui & Ben-Daya, 2009).

Emerging in the 2000s, predictive maintenance, which uses component reliability data to predict and plan future maintenance operations, is being used in increasing numbers (Tan, 2017). Nakagawa outlines that the importance of reliability engineering has recently increased with the production of good products of high quality and the design of highly reliable systems (Nakagawa, 2005).

The internal company organization of sound reliability engineering is an important matter. Various concepts exist for how reliability functions can be organized in a company. Kiran's House of Reliability illustrates the embedding of reliability engineering into an existing corporate structure in Figure 3. This depiction illustrates the strength that reliability engineering brings to an organization (D. R. Kiran, 2017).

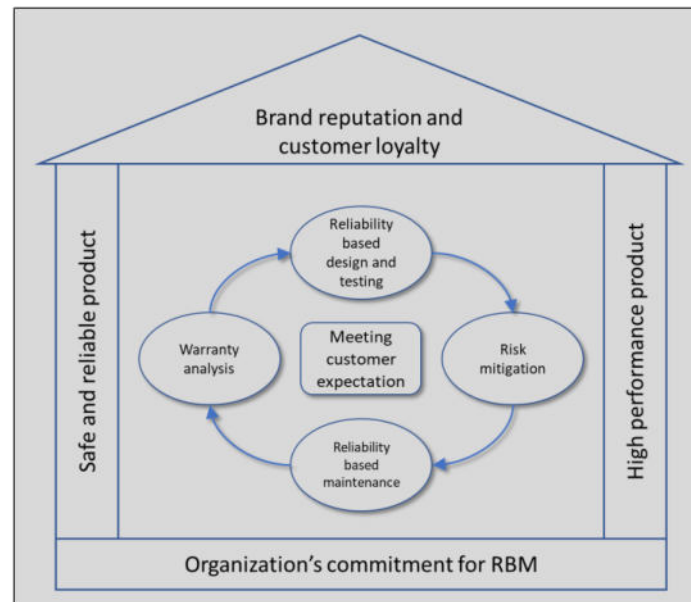


Figure 3: House of reliability (D. R. Kiran, 2017, p. 396)

Unfortunately, these organizational concepts are only exceptionally rarely detailed in the specialist literature. O'Connor and Kleyner state that several different activities contribute to the reliability of a product. Therefore, making categorical statements about the optimal organization is challenging to ensure effective reliability management. Reliability is influenced by many areas: design, development, quality control in production, control of suppliers and subcontractors, and maintenance (O'Connor & Kleyner, 2012). In their description, they delineate two distinct approaches to the organizational placement of reliability engineering within a company. One approach involves positioning it as a quality assurance-based organization, while the other involves its integration as an engineering-based organization.

Based on quality assurance, the first form transfers responsibility for reliability to quality management. This department then controls the "quality" of the design, maintenance, and production. The reliability engineering team works mainly with the technical departments, while quality control deals mainly with production. The organization in this form primarily uses companies that manufacture products for the commercial and domestic sectors. In the second organizational variant, the engineering-based organization, reliability is the responsibility of the engineering manager. This form of organization is more frequent in the United States (O'Connor & Kleyner, 2012). In a direct comparison of the two organizational variants, they elaborate further that the reliability organization based on quality assurance makes it easier to integrate some specific tasks. These are, for example, design, development, and production. Another aspect is that engineers with experience or qualifications in quality assurance are often familiar with reliability engineering methods. This is because the respective professional associations in North America and Europe have included reliability engineering in their areas of interest. Engineering-based organizations have distinct advantages when the products and systems require innovative design on a large scale.

In this case, a more significant part of the reliability effort must be directed toward design assurance, such as through stress analysis, design verification, or developmental testing. However, it is further emphasized that the chosen organizational form is much less important than the need to ensure integrated management of the reliability effort (O'Connor & Kleyner, 2012).

Calixto takes a slightly different view. He describes how it is much easier for reliability engineers to create a routine process if they have their organization's own

manager. A formal reliability management function to support other management areas, such as project, service, and operations management, is valuable to an organization (Fig. 4). This also gives reliability engineering a chance to succeed. Through this, reliability is not an additional activity for a few professionals but a formal activity within the organizational framework (Calixto, 2013).

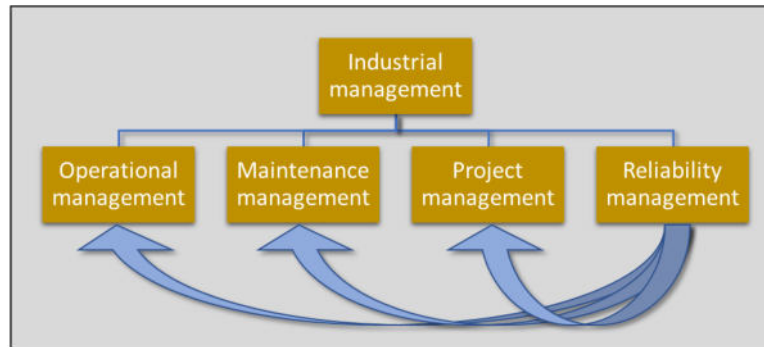


Figure 4: Reliability engineering management support, simplified visualization (Calixto, 2013)

Likewise, Blischke and Murthy describe how reliability overlaps with many disciplines. Researchers and practitioners in this area come from many different backgrounds (Blischke & Murthy, 2003). O'Connor and Kleyner make an important statement. They state that the essential requirement for a genuinely practical reliability function is that achieving high reliability is recognized as part of the corporate strategy. Top management must promote this (O'Connor & Kleyner, 2012).

Reliability engineering uses several standard mathematical and statistical tools in its work. In this regard, Smith explains that no human activity has zero risk. Likewise, no equipment has a zero-failure rate either. Based on this, a safety engineering approach has been adopted to optimize risk. This aims to balance the risk of a particular activity against its benefits. Likewise, the need for further risk reduction must be considered in terms of cost (Smith, 2011).

For work in reliability engineering, a solid database is an essential requirement. Calixto explains that having historical and failure data is essential to applying reliability engineering tools. The collection and analysis of data must be part of the maintenance process. These processes must be supported by management (Calixto, 2013). In this regard, Smith states that these may be collected in the real world or come from prototypes and production models. Formal defect reporting is required in either case. This is the only way to guarantee that the data remains

consistently accurate. Data from practice are more valuable for work since they relate to failures and repair activities that have occurred under actual plant conditions (Smith, 2011). Based on the available data, a product or system reliability assessment can be performed from a statistical point of view (Blischke & Murthy, 2000).

As previously mentioned, as part of the engineering process, reliability engineering focuses on the prevention, detection, and correction of reliability-related design failures, weak components, defects, etc. (Blischke & Murthy, 2000). Various standard methods are used in industrial reliability engineering to detect and correct these failures. Three of the basic ones are highlighted here.

Root cause analysis is used to find the fundamental reason for the failure. Blischke and Murthy describe it as follows: Each cause of failure is a symptom or consequence of the root cause. In a root-cause analysis, each element is analyzed in detail. In the root cause analysis, the question "Why?" is to be asked several times. No further questions are asked when a satisfactory explanation is found. Once the root cause has been identified, appropriate remedial action in the form of design changes or material selection can be implemented to eliminate the problem (Blischke & Murthy, 2000).

The Failure Mode and Effects Analysis (FMEA) identifies potential failure modes and effects and evaluates their impact. It is possible to evaluate entire systems, assemblies, or components. This type of analysis aims to identify the root causes of potential failures. Subsequently, preventive measures can be taken to avoid the identified failures (Kapur & Pecht, 2014).

The Fault Tree Analysis (FTA) is a reliability and safety design analysis technique. The process begins by considering the effects of system failures. Such are referred to as "top events." The analysis considers how single or multiple failures at a lower level can cause these. Standard symbols are applied to represent logical relationships and events. The method is integral to most safety analyses, as it can be used for multiple and single failure events (O'Connor & Kleyner, 2012).

In part of the related literature, the abbreviation RAMS is used for the concepts of reliability, availability, maintainability, and safety integrity (Smith, 2011). This concept originates from the fact that the techniques used in these areas can be applied to reliability engineering, safety engineering, and the optimization of

maintenance strategies. A distribution of measures compared to quality assurance in development over the past decades is shown in Figure 5.

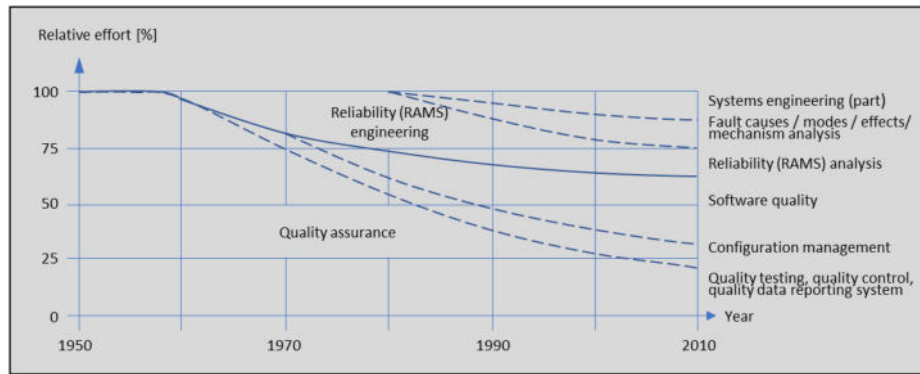


Figure 5: Approximate distribution of the effort between quality assurance and reliability (RAMS) engineering for complex equipment & systems with high quality and reliability (RAMS) requirements (Birolini, 2017, p. 17)

Birolini describes that crucial factors such as performance, reliability, cost, and time to market are essential for today's products and services. Due to increasing sustainability issues, ethical aspects have to be considered. Basic quality and reliability assurance rules, which are also optimized concerning cost and time planning, can be summarized. First, actual customer needs should be satisfied. The quality and reliability targets (RAMS) must be appropriately challenging to achieve this. Second, all activities to ensure quality and reliability (RAMS) should be carried out continuously in all project phases. This applies from the definition phase to the operation phase. Third, all engineers involved in the project must work closely together. Furthermore, all quality and reliability assurance activities (RAMS) should be supervised by a central quality and reliability assurance department. This department should actively participate in all project phases (Birolini, 2017).

As already described, reliability is closely related to the quality of a product. Commonly, reliability is considered a sub-area of quality. Basically, quality can be described as the extent to which the product meets the users' (customers') requirements. On the other hand, reliability describes a product's or system's functional life. Thus, a low-quality product is likely to have poor reliability, and a high-quality product is likely to have high reliability. However, reliability also depends on other external factors, not just quality. Still, reliability can be considered the quality of a product's operational performance over time. This consideration extends the quality to the time domain (Ebeling, 1997).

One of the concepts of reliability engineering is continuous improvement. There are two supporting methods for this purpose. Both can be used to improve reliability (plant uptime), but have different focuses:

- Total Productive Maintenance (TPM) – a human-centered methodology
- Reliability-Centered Maintenance (RCM) – an asset-centered methodology (Jardine & Tsang, 2013). Occasionally, it is also called reliability-based maintenance (RBM) (D. R. Kiran, 2017).

Steinborn states in his publication that various maintenance concepts have been introduced in the European industry in recent years. He names the two best-known maintenance concepts: reliability-centered maintenance and total productive maintenance (Steinborn, 2005).

The entire workforce is involved in the total productive maintenance concept. This maintenance philosophy incorporates the skills of all employees and focuses on improving the plant's overall effectiveness. A particular focus is on eliminating the waste of time and resources. In most cases, total productive maintenance is applied most straightforwardly to production equipment (Tamanacharya, 1998).

Jardine and Tsang describe that machine operators experience an expansion of their tasks in the form of performing routine service and minor repairs on their machines themselves (Jardine & Tsang, 2013). The main objective here is to avoid six major losses in plant effectiveness, as identified by Nakajima in 1988. These losses encompass breakdowns, the time required for setup and adjustment, idling and smaller downtimes, reduced velocity of operations, defects in the manufacturing process, and, ultimately, a lower overall yield. Nakajima's research highlights the importance of addressing these issues to enhance plant efficiency (Nakajima, 1988).

They further report that maintenance in the manufacturing industry accounts for approximately 15% to 40% of total production costs. It is estimated that at least 30% of these costs can be eliminated through total productive maintenance (Jardine & Tsang, 2013).

Reliability-centered maintenance is an alternative concept to the concept of total productive maintenance that relates to design improvement. It is a structured methodology to determine the maintenance needs of a physical asset in an operational context, where the asset under consideration may be part of a more extensive

system. The primary objective of reliability-centered maintenance is to maintain system function rather than keep an asset operational. In order to apply reliability-centered maintenance, there must be a comprehensive understanding of the functions of the equipment and the types of failures that occur. It is understood that not all failures are the same and that some failures cannot be prevented by overhaul or preventive replacement. Consequently, maintenance activities that are not cost-effective in maintaining system function are not performed (Jardine & Tsang, 2013).

According to Moubray, the concept of reliability-oriented maintenance aims to achieve its objectives by answering seven fundamental questions: The first question revolves around understanding the plant's functions and associated performance standards in its current operating context. The second question focuses on examining how the facility is not performing its intended functions. The third question is designed to identify the causes of functional failures. When a failure occurs, the fourth question examines the consequences and effects. The fifth question looks at the significance of each failure, the potential consequences, and the importance of maintaining the reliability of the plant. To improve reliability, the sixth question identifies proactive measures that can predict or prevent any failure. In cases where no suitable proactive measure can be identified, the seventh question comes into play. This is about what to do if traditional preventive measures are ineffective (Moubray, 1997). These seven questions form the basis of the reliability-oriented maintenance concept, which provides a structured approach to optimizing the reliability and performance of assets in different operational contexts.

Tamanacharya advises that reliability-centered maintenance is very demanding. This concept is not for every company. It requires a very knowledgeable maintenance team that has mastered basic preventive maintenance techniques and access to extensive machine data (Tamanacharya, 1998).

2.1.3 Maintenance – Existing Definitions, Functions, and Organisation

As already described in the introduction in the previous chapter, maintenance is an integral part of the corporate structure and, therefore, indispensable for the operation of an industrial manufacturing company. The DIN EN 13306:2018-02 is the specific standard within the European Union, issued by the European Committee for Standardization (CEN) (DIN Deutsches Institut für Normung e. V., 2018). This standard delineates the definition of the term "maintenance," emphasizing its

application throughout the life cycle of an object. Maintenance, as per this standard, encompasses a comprehensive set of actions to either sustain the object's condition or restore it to a state where it can effectively fulfill its intended function. As outlined in this standard, the concept of maintenance encompasses various activities, including observation, analysis, and actual maintenance actions, as elucidated by DIN (ibid.).

Historically, the implementation of industrial maintenance occurred in several waves. Along with the automation of manual activities, there was a high degree of machines to manufacture products and goods at the beginning of industrialization. These systems were usually mechanical systems with moving components such as shafts and levers. As a result, these systems were inevitably subject to wear and tear. Until about 1900, however, the maintenance tasks were not carried out by specially trained specialists but by production workers with manual skills (Gohres & Reichel, 2018). However, changes in the organization began to emerge in the following period. With the introduction of the separation of labor in manufacturing, a differentiation of tasks between production and maintenance employees also began to emerge. As a rule, only semi-skilled workers were employed in production. On the other hand, for the maintenance of the production plants, more and more employees were employed with specialized mechanical training and, with the increasing use of electric drives, also with specialized electrical training. This was when the first comprehensive maintenance instructions were drawn up, including maintenance and inspection plans (Gohres & Reichel, 2018). After World War II (from about 1950 on), maintenance became the focus of attention in the USA. The demand for industrial goods was high worldwide. Thus, the production of goods in demand had to be increased. The development leads away from the strategy of breakdown maintenance to preventive maintenance (ibid.).

In 1974, the DIN 31051 standard "Fundamentals of Maintenance" was published in Germany. For the first time, it comprehensively describes terms and procedures in maintenance. From 1990 onward, more and more companies in Germany went one step further. These companies introduced Total Productive Maintenance (TPM) (Gohres & Reichel, 2018).

Also, starting around 1990, many companies introduced PC-based maintenance planning and processing systems. A decade later, the chemical and petrochemical industries, in particular, are starting to use methods such as reliability-

centered maintenance (RCM) or risk-based maintenance (RBM) (*ibid.*). These maintenance tools help to perform the actual purpose of maintenance better.

The main objective of maintenance is to preserve the value of the assets and, thus, their serviceability. Industrial maintenance aims to achieve the longest possible trouble-free service life for the technical objects in its care. At the same time, the required effort should be kept as low as possible. Preventive measures in maintenance are primarily intended to reduce the wear rate (Strunz, 2012).

The objective of maintenance is to maximize uptime. Generally, the focus is on minimizing costs by identifying and eliminating cost drivers. Avoiding technically induced downtime is a usable manufacturing and operational production reserve. This reserve can be used to increase productivity (Strunz, 2012). The maintenance department can actively help achieve the production goals.

Producing goods while meeting the required productivity, quality, flexibility, and environmental goals is an essential company task. Maintenance is gaining importance due to increasing automation and the minimization of personnel deployment in production (Verein Deutscher Ingenieure, 2012). This unequivocally shows that maintenance is much more than an auxiliary function in the company. Its scope of activity extends to the area of production machinery and the maintenance of all property, plants, and equipment. In addition to land and buildings, this includes all machinery, equipment, tools, and devices, to name a few. Maintenance ensures the functionality of the entire infrastructure (directly and indirectly) involved in the process. The production facilities have the largest share in value creation and, therefore, have the highest priority. It remains to be stated that maintenance is not responsible for eliminating all disruptions. Production interruptions can also be of an organizational nature (missing tools, missing material), an informational nature (missing orders), or a personnel nature (illness) (Strunz, 2012).

The main types of maintenance are described in the standard DIN EN 13306. Based on this standard, these types are shown in a simplified form in Figure 6. The primary differentiation is made between improvement, preventive maintenance, and corrective maintenance. Preventive maintenance is further subdivided into predetermined maintenance and condition-based maintenance. There is also predictive condition-based maintenance and non-predictive condition-based maintenance to distinguish. Corrective maintenance can be divided into immediate and deferred corrective maintenance (DIN Deutsches Institut für Normung e. V., 2018).

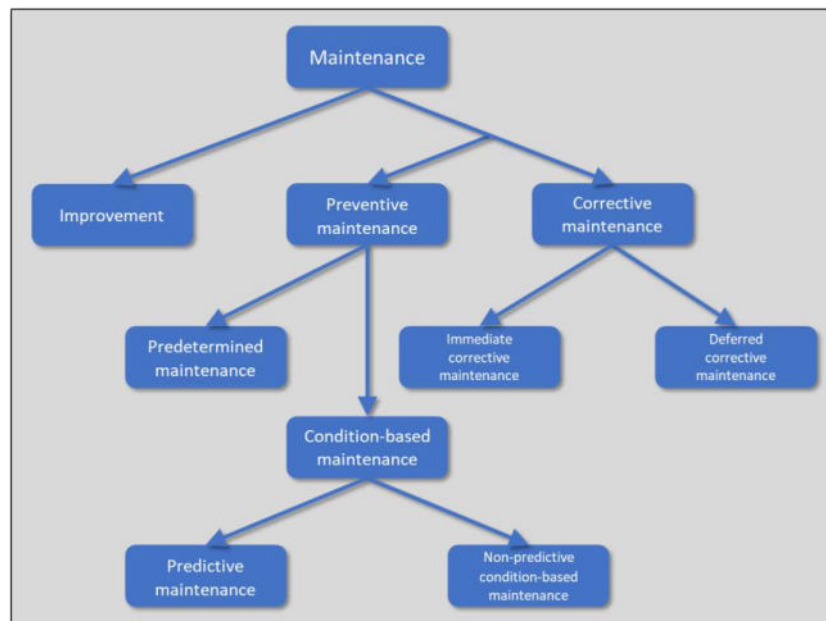


Figure 6: Main maintenance types, simplified illustration based on DIN EN 13306 (DIN Deutsches Institut für Normung e. V., 2018)

Blischke and Murthy state that a product's or system's performance depends on more than just its design and operation. The maintenance and repair of the item throughout its lifespan are also crucial. It is necessary to perform regular maintenance and service over an extended period to maintain proper function (Blischke & Murthy, 2003). Unfortunately, it is not always recognized that maintenance can permanently increase the production capacity of machines (Strunz, 2012). Implementing and planning such measures is an integral part of the maintenance organization. Strunz describes in his publication that ensuring equipment availability to achieve production goals is the most crucial task of the maintenance organization. Likewise, he states that the focus is on planned maintenance and not eliminating malfunctions and damage (Strunz, 2012).

The three basic types of maintenance (improvement, preventive, and corrective maintenance) are supplemented by further areas. Predetermined maintenance is a specific type of preventive maintenance. It is carried out at specified intervals or after a specified number of operating units. No prior condition assessment is performed (DIN Deutsches Institut für Normung e. V., 2018). Condition-based maintenance is also preventive maintenance. However, in contrast to predetermined maintenance, this also includes the assessment of the physical condition and

conducting analyses. The resulting maintenance measures are derived from this. There are different ways condition monitoring can be done. This kind of monitoring can be scheduled, on-demand, or continuously by operator monitoring.

Furthermore, condition-based maintenance can be done by inspection, different test procedures, or condition monitoring of the system parameters (DIN Deutsches Institut für Normung e. V., 2018). Condition-based maintenance can be divided into two parts. The first, predictive maintenance, is performed exclusively according to a prediction. The prediction can be derived from repeated analyses or from known properties and the determination of essential parameters that characterize the object's degradation. The second part contains non-predictive condition-based maintenance; however, it does not include a forecast of the degeneration of an object (DIN Deutsches Institut für Normung e. V., 2018). In addition, there are two different fields in the area of corrective maintenance. On the one hand, immediate corrective maintenance is carried out without delay after fault detection to avoid serious consequences. On the other hand, there is deferred corrective maintenance. The latter is not performed immediately after fault detection but is deferred according to predefined maintenance rules (*ibid.*).

As mentioned before, there are basically two types of maintenance: preventive and corrective maintenance. The implementation of maintenance measures is associated with additional costs. As the preventive maintenance effort increases, preventive maintenance costs increase as well, while corrective maintenance costs decrease (Fig. 7). The total expenses (preventive and corrective maintenance) plotted in the figure are convex. The lowest point is considered optimal (Ben-Daya et al., 2016).

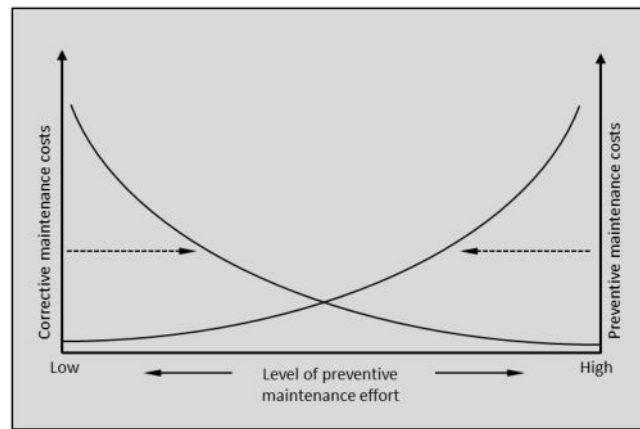


Figure 7: Preventive maintenance costs and corrective maintenance costs versus preventive maintenance effort (Ben-Daya et al., 2016, p. 13)

The strategic orientation of the maintenance process is usually based on a triangular relationship between reactive, preventive, and condition-oriented measures (Hodapp, 2018). Ito and Nakagawa specify that many researchers have already dealt with optimal preventive maintenance strategies. This is because the corrective maintenance costs of failure are much higher than the preventive maintenance costs. A well-designed, cost-effective preventive maintenance strategy can drastically reduce equipment maintenance costs. A detailed study of the target system's characteristics is required to find a cost-effective maintenance policy. Each stand-alone system has its own optimal maintenance policy with its unique characteristics (Ito & Nakagawa, 2009).

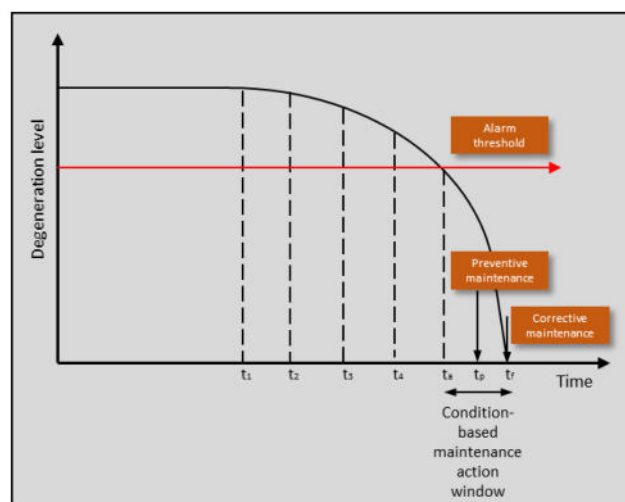


Figure 8: Concept of condition-based maintenance, slightly modified (Ben-Daya et al., 2016)

Condition-based maintenance helps determine the optimal time for maintenance through regular data recording. An example demonstrates this in Figure 8. Regular wear monitoring occurs at the times $t_1, t_2, \dots$. These are preventive maintenance measures to evaluate the condition. The inspection at time t_a (the first time after exceeding the alarm threshold) is the starting point of a condition-based maintenance time window. The point t_p represents a possible time for preventive maintenance action. In comparison, t_f is a failure time point if no condition-based maintenance action has been performed up to this point. After t_f , only a corrective maintenance action can be performed. This action is usually much more cost-intensive than the preventive maintenance measures that improve the condition (Ben-Daya et al., 2016). In this context, it must be considered that pure predetermined maintenance can only reduce the probability of failure through early replacement. As a result, the remaining service life is not used. Condition-based maintenance measures reduce the loss of useful equipment life. Therefore, these make more sense in operation than predetermined maintenance measures in advance. However, this advantage comes with additional technological costs (sensors for data acquisition, data analysis, modeling, etc.).

For this reason, condition-based maintenance is preferred for high-cost objects, while predetermined preventive maintenance is preferred for low-cost objects (Ben-Daya et al., 2016). Maintenance of the various types is accompanied by operational maintenance. The operational maintenance tasks can be divided into four key components. These are planning, control, the execution of maintenance tasks, and analysis. How the individual activities are interrelated is shown in Figure 9.

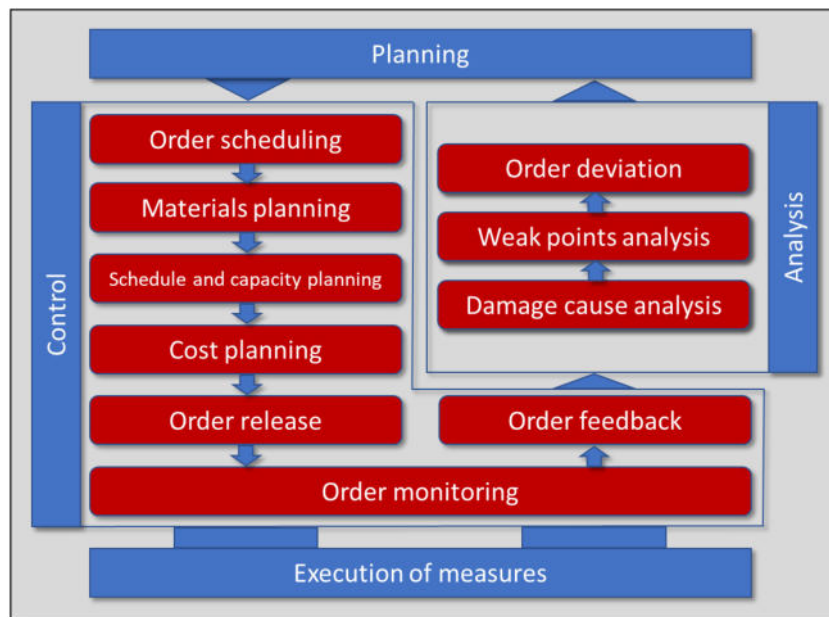


Figure 9: Components of operative maintenance management
(Verein Deutscher Ingenieure, 2012, p. 28)

Maintenance planning integrates the entire scheduled preparation of all maintenance activities into this framework. It includes budget planning, personnel planning, equipment planning, workshop planning, material planning, and work planning. Maintenance control is responsible for initiating, monitoring, and securing the processes required to perform maintenance tasks. As part of the execution of measures, maintenance activities are carried out on the objects to be maintained in accordance with the planning. According to the standards DIN 31 051 and DIN EN 13 306, maintenance activities include all technical and administrative measures and also management measures that are necessary during the life cycle of a unit under consideration to maintain its functional condition or to return it to this condition. Improvements that increase an object's functional reliability (e.g., by eliminating weak points) are just as much a part of this as service, inspection, and repair. Preventive measures include inspections and services. They aim to obtain information on the degradation of the wear margin or slowing it down in the case of service. Repairs or complete major overhauls can be arranged depending on the extent of wear. The area of maintenance analysis performs a retrospective object- and task-related evaluation of operations and facts according to different maintenance-specific aims and criteria. These include planned/actual comparisons (costs

and time), order deviation analyses, weak point analyses, damage cause analyses, and spare parts consumption analyses. This data is used, for instance, to determine maintenance workshops' capacity, calculate plant-specific key figures, and draw up budgets. Electronic data processing is particularly suitable for a larger number of maintenance objects (Verein Deutscher Ingenieure, 2012).

There are endless possibilities for how maintenance can be organized in a company. Industrial companies vary in their activities, size, degree of automation, number of employees, and degree of capacity utilization. This shows that there cannot be only one maintenance organization. Besides determining how to integrate it into the existing company, another consideration is whether the maintenance department should be partially or fully outsourced to external service providers. This possibility, in turn, raises new questions about the organizational structure. Various German and European standards and guidelines provide assistance. Important examples include "Grundlagen der Instandhaltung DIN 31051" (i.e., Principles of maintenance DIN 31051) (DIN Deutsches Institut für Normung e. V., 2019), "Organisation der Instandhaltung/Organisation of maintenance VDI 2895" (Verein Deutscher Ingenieure, 2012), and "Instandhaltung – Instandhaltung im Rahmen des Anlagenmanagements, Deutsche Fassung EN 16646:2014" (i.e., Maintenance – Maintenance within the scope of asset management, German version EN 16646:2014) (DIN Deutsches Institut für Normung e. V., 2015).

Each maintenance department follows a specific maintenance strategy. DIN EN 13306 describes the maintenance strategy as the management's process for implementing the maintenance objectives. This standard defines maintenance management as the set of managerial activities that establish requirements, objectives, strategies, and responsibilities, along with overseeing maintenance implementation. Through management, actions such as maintenance planning, control, and the improvement of maintenance activities and their efficiency are implemented (DIN Deutsches Institut für Normung e. V., 2018). This also influences the organizational structure to a considerable extent.

The primary organization is given as follows (Fig. 10):

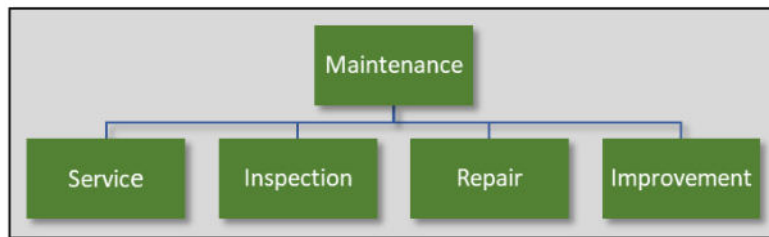


Figure 10: Subdivision of maintenance (DIN Deutsches Institut für Normung e. V., 2019, p. 12)

Haroun and Duffuaa describe the factors by which a maintenance organization and its position at the site and in the overall organization are strongly influenced. Here, the first factor is the type of organization. Is it a high-tech operation, a labor-intensive operation, a manufacturing operation, or a service operation? The company's objectives are also outlined. Are these profit maximization, increasing market share, or other social goals? The size and structure of the organization and its culture are also influenced. The scope of responsibility assigned to maintenance is equally decisive (Haroun & Duffuaa, 2009).

Maintenance must be seamlessly integrated into the company with a well-structured organization. Additionally, it is essential to define both structural and process frameworks. Maintenance task types and structures must be analyzed, maintenance workshops must be reorganized, and strategies must be optimized (Pawellek, 2016). The guideline VDI 2895 states that maintenance can generally be integrated into any company (Verein Deutscher Ingenieure, 2012). When creating a suitable organization, it must be considered that the focus was previously on the company's own maintenance organization and optimizing maintenance processes. Now, the focus is increasingly on maintenance processes and their integration into the production process (Huber, 2018).

Principally, three distinct organizational types can be identified. These include the single-line organization, the staff-line organization, and the multi-line organization, of which the matrix organization is a specific subtype. These can also be combined, depending on operational requirements.

The hallmark of a single-line organization is that an individual operating unit receives instructions from only one higher-level unit. There is a clear line of authority and responsibility from the top to the bottom of the organization. A subordinate unit never receives instructions from different higher units in a single-line

organization. However, it also follows that two instances of the same level in different lines may no longer work together directly. A deviation via the next jointly superordinate instance is always necessary. If superordinate instances are overloaded, there are often delays in decision-making. In small and medium-sized companies, single-line organization is widespread. The advantages, such as a streamlined organizational structure and a clear assignment of competencies and responsibilities, are counterbalanced by the disadvantages of long and cumbersome chains of command and the high workload of the higher levels (Pawellek, 2016).

In the case of a staff-line organization (Fig. 11), so-called staff units are assigned to the upper-line units for support. As a rule, these units do not have the authority to issue orders. By taking over preparatory and support activities, the positions of the instances are relieved without removing the uniformity of management and assignment. In maintenance, for example, the development of maintenance strategies, the preparation of the maintenance budget, the determination of the required personnel capacity, the preparation of work schedules, or the IT-supported administration and maintenance of maintenance data could be taken over. Beyond the primary benefit of reducing the workload at higher levels, task specialization among staff is also possible, facilitated by short communication paths. However, demarcating tasks and responsibilities between staff and the line is often difficult. Coordination of time and content between staff and lines is also a challenge (Pawellek, 2016).

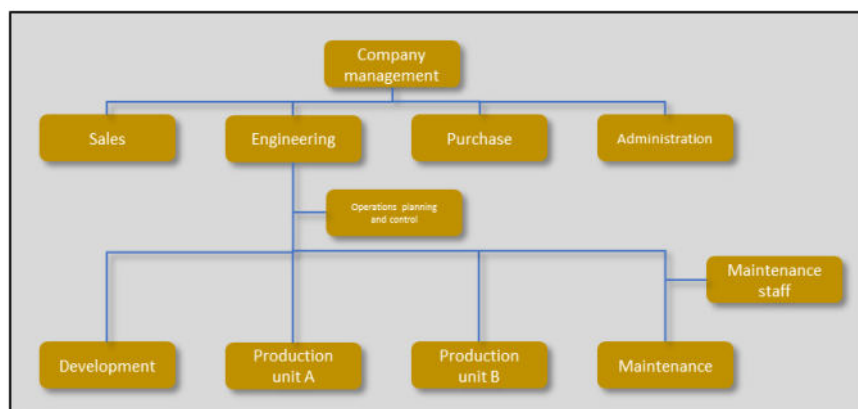


Figure 11: Functional organization as a staff-line system
(Verein Deutscher Ingenieure, 2012, p. 12)

The number of direct superiors distinguishes the multi-line organization from the single-line organization. A line instance receives instructions from only

one superior in a single-line organization. In a multi-line organization, each subordinate has at least two superiors. In this case, each supervisor is responsible for a specific task area and is authorized to give instructions to the subordinate for this delimited area. This avoids the cumbersome nature of the single-line system due to long decision-making paths. However, conflicts of competence often arise between the multi-line system's superiors since overlapping the various areas of responsibility cannot be avoided. Short communication channels and good coordination are achieved. The specialization of the performance task leads to qualitatively better decisions. However, there is a great need for information and communication and a high burden on the upper levels. This organization is susceptible to conflicts of competence because overall decision-making is often tricky (Pawellek, 2016).

The matrix organization represents a multi-line system (Fig. 12). Function-oriented and object-oriented organizational structures overlap. The executing unit belongs to both the task-related central maintenance area and the object-related product group area in the matrix organization. In principle, the matrix organization requires a higher level of coordination. This means that the conflicts that inevitably arise have to be managed. The main advantage is the possibility of dividing complex organizational structures into manageable units. There is qualitative relief from the top management.

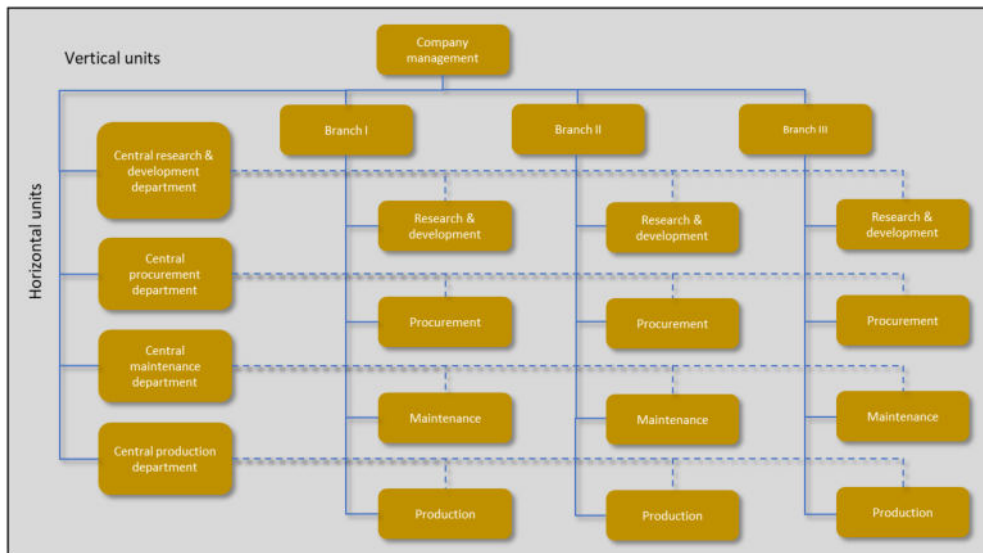


Figure 12: Matrix organization as a multi-line system (Verein Deutscher Ingenieure, 2012, p. 13)

The matrix organization is mainly used in large companies and requires a differentiated production program. There is a capacity balancing of personnel, which results in increased flexibility and short communication channels. The exchange of knowledge and experience is also promoted. However, conflicts arise due to the double assignment. A large number of management personnel are required (Pawellek, 2016).

2.2 STATE OF RESEARCH

2.2.1 Approach to the Selection and Review of Studies

Conducting a literature review is an essential part of any research project. A comprehensive overview is compiled and critically assessed to evaluate the relevant intellectual landscape, enabling the formulation of a research question that advances the knowledge base (Tranfield et al., 2003).

Fink suggests conducting a targeted literature analysis in seven steps. First, the research questions are formulated to guide the review's focus. This is followed by selecting bibliographic or article databases, websites, and other sources that can provide relevant data for the research questions. Search terms are carefully selected based on the terms and concepts that frame the research questions.

Practical screening criteria are applied to filter the set of relevant articles, including language, type of article, and publication date. Methodological screening criteria are used to assess the scientific quality of the selected sources. The actual review involves systematically reading, analyzing, and evaluating the literature using a standardized form. The synthesis of the results can be descriptive, with the interpretation based on the experience of the reviewers and the quality of the available literature (Fink, 2014).

The literature analysis for this thesis is based on this structured method to ensure that the analysis process is systematic and thorough. The application of this method guarantees well-founded and meaningful results of the literature analysis.

In order to follow Fink's approach, a first draft of the research question was presented in Chapter 1 - Introduction as an initial research question. Following this, the accessible databases for the analysis were determined.

For comprehensive research, various search engines and databases were considered to obtain diverse and credible information. The general Google search engine was used to create a broad overview of the topic. In addition, Google Scholar, a specialized tool for academic research, was used to search scientific literature, research papers, and academic publications. In addition, the EBSCO Discovery Service was used as a comprehensive database to provide centralized access to a variety of academic resources, including journals and books. This systematic approach, combining Google for general insights, Google Scholar for academic depth, and EBSCO for comprehensive resources ensured a thorough exploration of the chosen topic and ultimately contributed to a solid outcome.

In the following third step, suitable search terms had to be determined. These should narrow the subject area but not restrict it. Tranfield, Denyer, and Smart explain that a methodological study begins with identifying keywords and search terms that the researcher determines to be the most appropriate search terms for the study (Tranfield et al., 2003). The keywords used were derived from an initial review of the known specialist literature on the research topic prior to the systematic literature search. In order to keep the number of results as high as possible, the search was first carried out with US-English search terms and then with the corresponding German search terms. The German terms are given in brackets below. The initial search terms were business administration (Betriebswirtschaftslehre), maintenance (Instandhaltung), and reliability engineering (Zuverlässigkeitstechnik). These search terms had to be narrowed down further during the search. In the area of business administration, the search terms used were cost savings and increasing profits. In the context of maintenance, the search terms focused on organization, cost, and cost efficiency. In the field of reliability engineering, the search terms software and network were excluded. All search terms were used in various combinations (both inclusive and exclusive).

In the fourth step, practical criteria for searching were established. As per Fink's recommendation, initial literature searches often yield many articles, but only a select few are pertinent (Fink, 2014). Applying practical search criteria is important to refine the search results from the outset. As mentioned earlier, the focus is exclusively on literature in English or German, without imposing restrictions on electronic or printed resources. It is presumed, however, that the literature is generally accessible in electronic form. The search aims to procure the most recent

sources, preferably not exceeding a five-year timeframe. Nonetheless, given the highly specialized nature of the topic, flexibility in this criterion is acknowledged. Another objective is to primarily utilize articles from reputable scientific journals, especially peer-reviewed ones. Should there be an insufficient number of articles in these journals, the scope of acceptable literature forms may be expanded. Likewise, studies whose results are based not only on a literature review but also on empirically determined figures or at least on one or more case studies should be identified.

In the fifth phase, methodological criteria must be established to assess the scientific stringency of the selected materials. It is presumed that articles of high scientific quality will be encountered by relying primarily on scientific journals. Papers that do not meet this criterion can still be considered if they are particularly relevant to the topic.

The sixth step that follows focuses on executing the literature review. During the literature review process, it became evident that there was an overlap in the pertinent findings across the respective databases. The overall results from a standard Google search yielded a substantial number of outcomes. In comparison, Google Scholar provided a lower count of results. Additionally, the search conducted on the EBSCO Discovery Service platform produced fewer results.

The following numerical representations illustrate the search procedure. These are examples taken from a search on the EBSCO Discovery platform. It is important to recognize that the raw numbers offer only a broad overview of the field. These numbers are not meaningful in terms of scientific content. All relevant papers were then individually reviewed and checked for eligibility.

The initial searches across various fields yielded a substantial number of hits, as illustrated by the following figures: 3,818,665 hits for "business administration" (131,887), 7,773,408 hits for "maintenance" (32,912), and 1,661,530 hits for "reliability engineering" (70). Notably, the frequency of hits was generally higher for English terms than their German counterparts. To refine the search and focus on specific aspects, the terms "savings" and "increasing profits" were progressively incorporated into the "business administration" category. This adjustment substantially

reduced search hits, decreasing to 631,247 (1,923) and eventually reaching 174,017 (172).

Following this, a similar strategy was applied to exclusive keyword searches. The inclusion of "savings" and "increasing profits" led to a substantial decrease from 81,606 (4,424) to 234 (0) and ultimately to 6 (0) hits. Further refinement involved conducting a pure title search for "business administration," which was succeeded by searches for "business administration" with the addition of "savings." These modifications resulted in hits numbering 5,563 (1,365) and 3 (0), respectively.

The exploration then shifted to the "maintenance" term, employing a systematic approach. Initial restrictions involved adding the words "organization" and, subsequently, "costs," resulting in hit counts of 1,972,310 (22,938) and 1,129,444 (4,202). Subsequent keyword searches for "maintenance" with "organization" and further supplemented with "costs" led to reduced counts of 33,631 (40) and 3,345 (2). A title-only search for "maintenance" and "organization" produced 2,815 (16) hits, and the addition of "costs" further reduced this to 895 (1). A specific search for "maintenance," "organization," and "cost-efficiency" yielded 26,402 results, while an exclusive keyword search resulted in 6 hits.

In the case of "reliability engineering," the initial hits were comparatively lower. By excluding the words "software" and subsequently "software" and "network," the hits were reduced to 998,652 and 651,637, respectively. Given the German term's limited hits in the first search (70 across all fields), further restrictions were not applied. Subsequent keyword searches for "reliability engineering" alone, followed by exclusions of "software" and "software" plus "network," produced hit counts of 70,279, 56,524, and 43,939, respectively. Exclusive title searches following the same exclusion order resulted in 1,968, 1,446, and 1,322 hits. For a detailed compilation of the search, refer to Appendix 8.2 of this dissertation.

The research findings underwent further refinement in accordance with the criteria outlined in the fourth step and were subsequently assessed for relevance through multiple stages. In analyzing the content of well over a thousand studies, it became evident that the initially specified requirements were challenging to fulfill, given the niche nature of the topic. To identify studies with relevant content, it became necessary to consider articles from less rigorous journals, where results were not exclusively based on empirical data or case studies. Additionally, an extension of the publication period was deemed essential. The 59 studies identified

as relevant to the research topic were obtained from the libraries of Universidad Católica San Antonio de Murcia (Spain), FOM University of Applied Sciences (Germany), and the University of Duisburg-Essen (Germany), along with various other reputable scientific sources. The seventh and concluding step, where the results are synthesized, occurs in the subsequent sub-chapter.

2.2.2 Results of the Study Review

An examination of the research situation on this dissertation topic reveals considerable heterogeneity. As explained in the previous section, there are many scientific articles on general terms, particularly in the context of maintenance and business administration. However, the number of these works decreases rapidly when the topic is further specified.

The selected relevant studies typically focus on precise details of the subject area. Sometimes, only certain aspects of a study are of particular interest. Of the total of 59 carefully analyzed studies, eight particularly revealing studies from this research area are now presented as examples. Finally, this sub-chapter presents a comprehensive analysis of the results of these studies.

In his paper, "Improving the foundation and practice of reliability engineering," Aven summarizes the current state of reliability engineering by evaluating the available scientific written sources. He also highlights that the existing theoretical models in this field are not always easily applicable in practice. From this, he concludes that there is room for improvement in both academic and practical domains. His article is aimed at reliability engineers and people in key positions in their respective companies. The study finds that clarifying concepts and further developing principles, methods, and models for understanding reliability and determining the "right" level of reliability are needed. In this regard, the study offers some guidance (Aven, 2017).

In their paper, "Optimization of condition-based maintenance considering partial opportunities," Truong-Ba, Borghesani, Cholette, and Ma describe the economic benefits of a strategy to exploit partial maintenance opportunities. These benefits result from reducing partial maintenance costs when the opportunity is exploited. To this end, a condition-based maintenance strategy is presented under

time-varying economic conditions. In addition to this approach, this study includes analyzing a set of imperfect maintenance actions with uncertain recovery rates. The total expected maintenance costs for the maintenance actions were minimized by applying the Markov decision process. The system degradation thresholds for different preventive maintenance actions and opportunistic maintenance selection were jointly optimized in this process. A realistic case study was conducted to verify the presented measures. The authors conclude from the applied case study that the proposed strategy can achieve considerable savings of up to 50% under long-term conditions. Under short-term conditions, substantial savings of 3–7% are also possible. Here, the numerical results underscore the hypothesis that savings are more pronounced when the cost of lost production is high, and the chances of opportunities are higher (Truong-Ba et al., 2020).

Emblemsvåg and Tonning describe in their paper, "Decision support in selecting maintenance organization," that it is difficult to find a satisfactory maintenance organization when focusing on costly and technologically advanced equipment with long service life. There are many goals to be achieved here, and these can change. In particular, there are several fuzzy and multi-dimensional decision criteria with a high degree of uncertainties and risks. They describe how the so-called analytical hierarchy process is applied to determine the preferred maintenance organization. The paper focuses on supporting decision-makers in the organization. During the course of the paper, the proposed decision process is illustrated with a very concrete example. A Monte Carlo simulation was also used in a supportive manner for this purpose. The authors show in the study that the decision process is a robust approach to capturing all opinions through the parallel application of the Analytic Hierarchy Process and a Monte Carlo simulation. Thus, a high level of acceptance of the respective decision can be generated. In addition, the decision process is documented in a standardized manner (Emblemsvåg & Tonning, 2003).

In their study, "Reducing costs by clustering maintenance activities for multiple critical units," de Jonge, Klingenberg, Teunter, and Tinga describe the possibility of saving maintenance costs by bundling maintenance activities. Major advances in sensor technology have also enabled companies to make vast improvements to condition-based maintenance. However, there is the potential for increased maintenance frequency at the unit level, which can increase costs. The

authors argue that savings can be made not by delaying maintenance but by merging maintenance activities. For this purpose, two simple systems with different warning thresholds were evaluated. It is proved with mathematical methods. In a depicted test on a real-life case study, the savings possibilities of the total maintenance costs are verified (de Jonge et al., 2016).

Sailer and Hladík's study, "Consistent Maintenance Management Model: Results of Changes of Maintenance Organisation Structure and Processes," reports that industrial companies use different organizational approaches for asset management processes. These approaches also result in different target achievements for key performance indicators. Various real examples of maintenance process models from different industrial sectors are summarized, evaluated, and presented (as benchmarks). Organizational changes in the respective companies should increase the maintenance organization's overall efficiency, especially in management, which should also lead to a quantitative improvement of the required key performance indicators. The authors demonstrate that a 25% reduction in maintenance management staff was possible. Over a more extended period, it was also possible to demonstrate that the key performance indicators under consideration improved continuously (Sailer & Hladík, 2021).

Salonen and Deleryd discuss in their paper, "Cost of poor maintenance: A concept for maintenance performance improvement," the cost of poor maintenance (CoPM) as a concept for managing maintenance performance improvement in the manufacturing industry. They explain that the concept is based on well-established quality costing practices. The concept presented is intended to be applied to identify deficiencies in maintenance performance within a given manufacturing system. Its purpose is to demonstrate what maintenance costs are appropriate and what portion of the costs are due to poor performance. The concept shows the financial contribution of maintenance activities. This should be shown at the board level, in particular. The study is based primarily on a literature review, but two workshops were also held to confirm the approach. The results were mainly positive (Salonen & Deleryd, 2011).

Vishnu and Regikumar explain in their paper, "Reliability Based Maintenance Strategy Selection in Process Plants: A Case Study," emphasizing that plant maintenance is vital to determining productivity. Plant maintenance aims to minimize downtime and maintain good operating conditions at low costs. Therefore,

selecting a maintenance strategy is a vital decision for a company. The authors present a general approach for implementing reliability-centered maintenance (RCM) in process plants. In the application of RCM, the most appropriate maintenance strategy for all equipment in the plant is selected using various parameters. The study is based on a literature review. The results found are then applied to a real-life case study and presented. The case study confirmed the methodology used to identify the optimal maintenance strategies for each piece of equipment or machine based on its criticality (Vishnu & Regikumar, 2016).

In the scientific article "Advanced model for maintenance management in a continuous improvement cycle: integration with corporate strategy," the authors Barberá, Crespo, Viveros, and Stegmaier state that maintenance strategies should always be in line with the company's business plans. Their proposed model makes aligning maintenance goals with overall business objectives possible. Based on a literature review, they highlight the importance of proper maintenance management and its processes. They then describe a seven-step model. This model explains how all processes involved in maintenance can be managed and continuously optimized. Furthermore, the fundamental principles that align maintenance activities with the company's policies are implemented. Following the study, the model was implemented in various industries (Barberá et al., 2012).

The vast majority of studies also look at very detailed sub-aspects of the areas of maintenance and business organization. The majority of them have firm business references. Firstly, this can be very direct so that maintenance costs can be reduced (for example, Bensmain, Dahane, Bennekrouf, and Sari (Bensmain et al., 2019) and Hasanah and Wulandari (Hasanah & Wulandari, 2019) or, secondly, indirect so that uptime can be increased or production losses can be reduced, and thus the company's profit increased. Liao, Chen, and Yang (Liao et al., 2017) and Liu, Wang, and Peng (X. Liu et al., 2017) represent this procedure as an example. Thirdly, various authors have dealt with improving the efficiency of the existing maintenance structure within the framework of a company, thus achieving better performance and improvement. Sinha (Sinha, 2015) and Erbe, Iung, and Morel (Erbe et al., 2007) may be mentioned here as representatives.

A direct comparison of the individual studies and their results is only statistically reliable for a few journal articles due to the extensive differences in the

unmanageable field of optimization possibilities in maintenance and production. Nevertheless, some commonalities are recognizable in the totality of the set of considered studies. It is apparent that many of the studies aim to improve the processes of individual, sometimes particular, and occasionally minimal areas of the process organization within the production or maintenance department. For example, be listed here: Kimera and Nangolo (Kimera & Nangolo, 2020) or Hafidi, El Barkany, El Mhamedi, and Mahmoudi (Hafidi et al., 2020). Here, there is also a particular preference to look at and optimize aspects of preventive maintenance, such as Rosqvist, Laakso, and Reunanen (Rosqvist et al., 2009) or Kilic, Ali, Weber, and Dubey (Kilic et al., 2014). Due to this diversity, almost every study poses a very different research question. A further meaningful and explanatory compilation of the studies examined does not appear to be purposeful here.

In all of the present studies, the authors conducted literary research, in some cases very briefly as a database. Some of the papers rely exclusively on the evaluation of specialized literature; for example, Navas, Sancho, and Carpio (Navas et al., 2020) or Farahan and Tohidi (Farahani & Tohidi, 2021). However, most studies have additionally conducted case studies, proposed various models, or conducted a simulation. Likewise, well over half rely on mathematical models in their work. Occasionally, they are supported by case studies. Some case studies are hypothetical and do not refer to actual data. The exact representation of the methods used is shown in Figure 13.

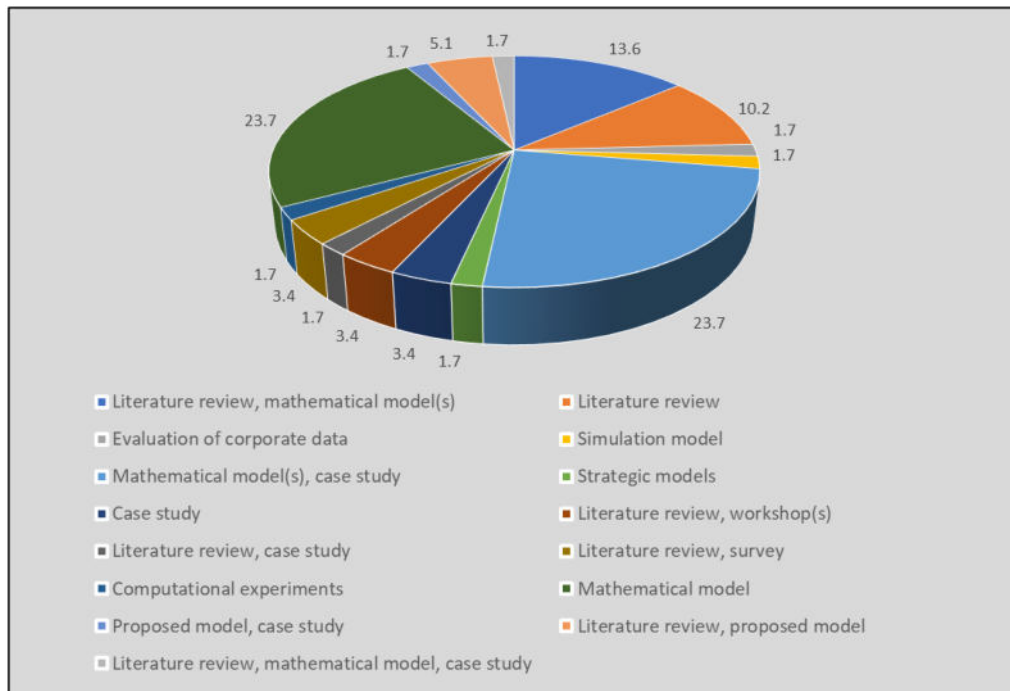


Figure 13: Methods used in the studies investigated [%]

When looking at the sample size, it is noticeable that the majority of the studies do not rely on empirical figures but rather on theoretical simulations. As many as 76.3% of the studies considered using only theoretical data (for example, Altehmazi, Suliman, and Alalawi (Altehmazi et al., 2017)). However, most studies that use real numbers only use values from one company (e.g., Bohlin and Wärja (Bohlin & Wärja, 2015)) or just one real case study (e.g., Besnard, Fischer, and Tjernberg (Besnard et al., 2013)). Only 3.4% of the studies had a participant size larger than 100 (e.g., Belekoukias, Garza-Reyes, and Kumar (Belekoukias et al., 2014)). Depending on the research question, the participant count varied between 9 and 150 in one study (Idhammar, 2009). One study's exact number of participants was unclear (Siew, Ong, and Nee (Siew et al., 2021)). These data are shown in the diagram below (Fig. 14).

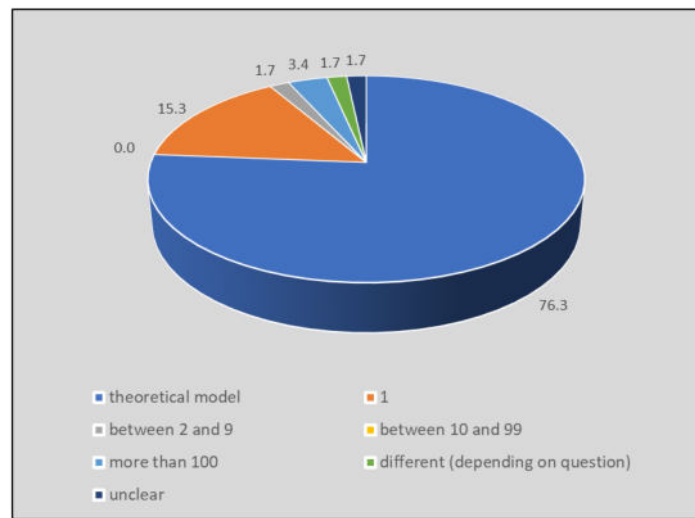


Figure 14: Sample size in studies investigated [%]

The results are very different as they are understood, just like the questions posed in the scientific papers. However, it can be shown that all studies could adequately answer the initially posed question. When looking at the results, it is also clear that the overwhelming majority of the studies indicate their main result as the possibility of reducing costs. This is true for 71.2% of the work evaluated in various depths and characteristics. In 15.3%, the result refers mainly to relevant organizational changes or adjustments within the organization. In addition, 13.6% represent other meaningful results. For example, these can be the successful application of theoretical calculation models (e.g., Paprocka, Kempa, and Skołud (Paprocka et al., 2021)) or the successful representation of new technologies in maintenance engineering (Navas, Sancho, and Carpio (Navas et al., 2020)). These data are summarized in Figure 15.

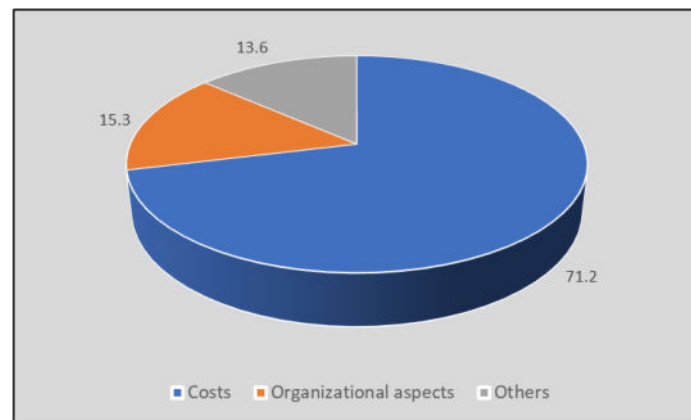


Figure 15: Research results [%]

2.2.3 Discussion of the State of Research

Many researchers indicated the need for further research as part of their study. In the case of the examined studies, this concerns 61% of the papers.

Extension of Work

Some authors indicate that further development of the calculation model seems appropriate. Faddoul, Raphael, and Chateauneuf (Faddoul et al., 2018) can be mentioned as examples. Likewise, Vilarinho, Lopes, and Oliveira (Vilarinho et al., 2017) indicated that developing a computer application that integrates into the existing computer system seems to be a given. Several other authors suggest a further expansion in the sense that an application of their study is carried out in more complex situations. Liu, Dong, and Chen (Q. Liu et al., 2018) describe, for example, that the model they propose should be extended, in the course of further research, to highly flexible systems with multiple machines as well as to service systems. Rivera-Gómez, Gharbi, Kenné, Montañó-Arango, and Corona-Armenta (Rivera-Gómez et al., 2020) also state that the next step in their work would be to investigate more complex production systems. In principle, a similar proposal is made by Marchi, Zanoni, and Jaber (Marchi et al., 2019). The authors propose extending their work to studying a complex production network or a model in a supply-chain context.

Validation needed

Several authors in this field stress the need for further research and validation to enhance the credibility and reliability of their findings. For instance, Tannock and Saelem highlighted in 2007 the necessity of refining and validating the extent and behavior of disruption costs, particularly through empirical data (Tannock & Saelem, 2007). Likewise, Licandro and Puch emphasize the importance of additional research to either confirm or challenge the behavior of their model (Licandro & Puch, 2000). The fact that both teams of authors acknowledge the ongoing need for research suggests that they are committed to ensuring the robustness and accuracy of their work.

In both cases, the authors appeal to the scientific community to engage in collaborative efforts to improve the understanding and validity of their research findings. This emphasizes scientific progress's iterative and collaborative nature, where researchers are encouraged to work together to expand and refine knowledge in their field continually.

Continuation of Work

In scientific research and methodology, it is common for scholars to provide clear and specific guidance on advancing a particular field of study. In this context, Braglia, Fantoni, and Frosolini, as documented in their 2007 publication, emphasize the critical importance of developing precise scales and employing mathematical tools as essential components for furthering their work (Braglia et al., 2007). Their assertion underscores the significance of rigorous measurement and analytical techniques in pursuing scientific knowledge. Similarly, in their 2020 work, Zhou and Yu contribute to the discourse by highlighting the necessity of enhancing the definition of maintenance time windows for individual stations (Zhou & Yu, 2020). This recommendation underscores the importance of refining temporal parameters to optimize operational processes and efficiency within their domain of study. Such clarity in specifying the direction for future research is integral to advancing any scientific discipline, ensuring that subsequent investigations build upon established foundations and contribute meaningfully to the body of knowledge.

Modification of the initial Parameters

Various sources emphasize multiple times that the model under consideration should be subject to rigorous examination by manipulating its parameters. This involves the deliberate adjustment of values, both increasing and decreasing them, to explore the model's behavior under different conditions. This recommendation is made by several researchers, including Wang, Lin, Fu, Luo, and Chen (Wang et al., 2020) work and Maji, Bhunia, and Mondal (Maji et al., 2020).

This approach is crucial as it offers valuable insights into the model's robustness, sensitivity to various inputs, and overall performance across different scenarios. By systematically adjusting parameters, researchers can better understand how the model reacts to varying conditions, allowing them to identify potential limitations, weaknesses, and areas for improvement. This iterative process of parameter exploration is a fundamental aspect of refining and improving the model's capabilities to ensure that it remains effective and reliable in real-world applications.

Others

Conversely, Aven broadly asserts that additional research is necessary to equip reliability engineering for future challenges (Aven, 2017).

A number of the authors name in their articles, beyond the recommendations for further research, other difficulties in the scientific fields considered. For example, Shahraki, Yadav, and Vogiatzis describe that for some systems, it is crucial to determine the optimal maintenance actions for real-world problems (Shahraki et al., 2020). Erbe, Iung, and Morel indicate, from the technical point of view, that in the operations, most of the data from sensors that monitor the condition and performance of the machine are hardly or not used at all (Erbe et al., 2007). There are also further references to difficulties in Madu's text. He asserts that reliability is viewed as a technical problem. However, he specifies that top management must understand that reliability management directly impacts overall organizational effectiveness (Madu, 2005). When looking at the work "Maintenance concept development: A case study" by Waeyenbergh and Pintelon points out the absence of a systematic and coherent approach to developing and implementing a maintenance concept (Waeyenbergh & Pintelon, 2004).

As mentioned earlier, it appears that many researchers have looked at very specific aspects in particular detail, sometimes in great depth. What is striking is that no holistic, modern, and contemporary organizational concept of maintenance in the context of an industrial company is presented. Also missing is a consideration of the cost level. If information is available in this area, it is usually only superficial. Careful consideration of reliability engineering tasks and their meaningful embedding in the organizational context remains open. In fact, details in the field of reliability engineering are rarely examined in depth. For example, the presentation of a company's positive or possibly negative reliability engineering context is missing. Why have some companies introduced such a department, and what specific activities are carried out there? It is particularly striking that only a fraction of the studies examined are based on empirical data obtained from a sufficiently large sample.

Although it was previously known that research in industrial reliability engineering was breaking new ground and had only been explored to a limited extent, the extensive literature review revealed that a considerable number of fundamental questions remained unanswered. These questions span several key aspects of this field and, in particular, include fundamental data gaps. For example, it was not possible to find explicit confirmation of the types and sizes of operations in which REDs have primarily become established. The composition of the workforce in these departments relative to general maintenance also remained an open mystery, as did the question of these employees' qualifications and training standards.

At the organizational level, the question of how existing or planned REDs would be integrated into the general company structure remained unanswered. It is unclear whether these departments operate independently or are integrated into other business units. The choice of maintenance strategy in firms employing REDs also remains obscure. Another major concern relates to the type of employees employed in the reliability engineering area. It is unclear whether they are full-time or part-time and how this impacts their effectiveness.

Although the literature provides detailed descriptions of the duties and responsibilities of REDs, it remains uncertain whether they are implemented this way in practice. There is a noticeable lack of concrete examples and case studies demonstrating the application of these concepts. The financial side of reliability

engineering has also been neglected in the literature. There is a lack of information on what proportion of the maintenance budget is spent on reliability engineering tasks. Similarly, the expectation of achievable savings over a RED remains unclear. This is not exclusively about monetary savings but rather about savings of all kinds. There is no indication whether these expectations can be met in practice or whether the savings are only theoretical. Overall, the literature review indicates a need to conduct further research and investigation in industrial reliability engineering to address these fundamental knowledge gaps and provide a better foundation for further research.

The discussion on the state of research in industrial reliability engineering highlights several recurring themes. Firstly, one key observation is that most researchers emphasize the need for further studies in their respective areas. Examples of this include the call for the development of computational models, the integration of computer applications, and the extension of the study to more complex scenarios. Secondly, validation is repeatedly emphasized as crucial to strengthening the credibility of the results, with authors such as Tannock and Saelem (Tannock & Saelem, 2007) emphasizing the refinement and validation of behavior in the presence of disruption costs. Thirdly, researchers such as Braglia, Fantoni, and Frosolini (Braglia et al., 2007) emphasize the importance of clear guidelines for future research directions and value precise scales and mathematical tools in their work. Finally, changing the initial parameters is emphasized by several researchers, including Wang et al. (Wang et al., 2020) and Maji et al. (Maji et al., 2020), as a method for examining model behavior, assessing robustness, and identifying potential improvements.

Despite these commonalities, there are gaps in the literature. Specific questions about the operation of reliability engineering departments in the industry remain unanswered. Data gaps include information on the type and size of companies where REDs are established, the composition and qualifications of the workforce, and how these departments integrate into the organization's overall structure. In addition, the literature lacks clarity on the choice of maintenance strategy, the nature of employment, the implementation of RED concepts in practice, and financial aspects such as budget allocation and achievable savings. These gaps

highlight the need for further research to understand and fully address the challenges of industrial reliability engineering.

3 PRELIMINARY STUDY: CURRENT STATE ANALYSIS

Through the current state analysis, it is intended to get closer to the field of investigation with its existing gaps. The research area under consideration is a very limited, highly specialized field. This is also reflected in the fact that there are virtually no research results in this area and only very few meaningful studies and articles in professional journals. The available literature reviewed is incomplete concerning the field under investigation and only provides little detail, as described in Chapter 2.2 - State of Research. In order to counteract this circumstance, a current state analysis of the field of reliability engineering will first be conducted within the scope of this thesis. Through this descriptive quantitative preliminary study, new knowledge should be gained. This is intended to close existing gaps and provide a foundation for the main research and the development of a concrete research question with the corresponding sub-questions based on the new data.

3.1 DATA BASIS AND SAMPLING

The sample's representativeness for a population is influenced by the sampling frame, the sample size, and the specific methodology of the selection procedures (Fowler, 2014). Principally, quantitative empirical social research is focused on the highest possible number of cases or at least a sufficient number for specific statistical purposes. Studies with a limited number of cases are susceptible to concerns about biased selection (Jungbauer-Gans, 2009). Therefore, the survey must include a sufficiently large number of participants to allow for meaningful conclusions about the majority within the specialized field. The required target population for the survey is necessarily limited to a well-specialized group of participants, which is essential for a competent and accurate response. Profound knowledge of the specific processes, procedures, and costs of at least one production site is required. A clear and specialized understanding of reliability engineering is also crucial.

This study's survey includes diverse participants, including general managers, site managers, production managers, maintenance managers, reliability managers, reliability engineers, and other professionals with similar expertise in the area. The target population for this research presents a specific constraint. The

primary requirement for participants is that they possess knowledge and insights related to the manufacturing industry. This criterion ensures that those included can contribute valuable information pertinent to the study's objectives. However, minimal restrictions beyond this fundamental requirement are imposed on the participants. The research does not demand that participants belong to any particular industry sector or a specific geographic location. This broad inclusivity allows for diverse perspectives, as companies of varying sizes and locations can participate. Moreover, the research extends its invitation to participants worldwide, emphasizing its global scope and reach. Geographical boundaries are not a limiting factor in selecting participants, further enhancing the breadth and diversity of the data. Additionally, the research does not require that participating companies must have already established a reliability engineering department (RED) or be in the planning stages to do so. This lack of constraints ensures that the study can capture a wide range of experiences and insights related to established or emerging REDs. In essence, the approach to participant selection is intentionally open-ended, allowing for as little restriction as necessary. This inclusivity is designed to gather a comprehensive and varied dataset, facilitating a more holistic understanding of the manufacturing industry and its relationship to reliability engineering.

The sampling frame describes all units in the population from which the sample is selected (Bell et al., 2019). Due to the limited research in this field, obtaining reliable data is challenging. Nevertheless, evaluations have shown that 6,989 people in the United States of America were employed as reliability engineers as of July 21, 2023. Of these, 75% work in companies with more than 1,000 employees. Furthermore, it can be concluded from the analysis that approx. 52% (3,634) of the reliability engineers work in the industrial environment, which is exclusively considered here (*Reliability Engineer Demographics and Statistics in the US*, 2023). Obtaining comprehensive and dependable data on companies that maintain a reliability engineering department, as well as the actual number of employees engaged in this specialized field, has proven to be a challenging endeavor. A total of 58 government agencies and professional and industry associations were contacted with requests to provide reliable data for the preliminary study. Likewise, a very pervasive Internet research was carried out. Despite the enormous efforts invested in this pursuit, the information remains elusive. This data scarcity applies to various sources, including government agencies and private associations. Governmental entities,

like the German Federal Statistical Office and the British Employment Agency, for example, have been unable to provide substantial data regarding the prevalence of reliability engineering departments within companies or the size of their respective workforces in this domain. This lack of information from authoritative sources at the national level has added to the complexity of assessing the landscape of reliability engineering within the corporate world.

Similarly, private associations and professional societies dedicated to maintenance and reliability, such as the Society for Maintenance & Reliability Professionals in the United States and the Association of German Engineers (i.e., Verein Deutscher Ingenieure) in Germany, to name only two, have also encountered difficulties in collating detailed and up-to-date statistics. These organizations typically serve as valuable repositories of industry-specific data, yet even they have faced challenges in gathering comprehensive insights into the prevalence and scale of reliability engineering endeavors. The reasons for the scarcity of this data may be multifaceted. Companies may not systematically report on the presence or size of their reliability engineering departments, and there may be variations in how organizations define and categorize roles related to reliability engineering. Additionally, some firms might consider such information sensitive or proprietary and refrain from disclosing it publicly. In summary, such information remains frustratingly elusive despite earnest efforts to compile comprehensive and reliable data on companies with reliability engineering departments and the actual workforce in this field. The absence of such data from governmental and private sources underscores the need for continued research and collaboration within the reliability engineering community to shed light on this vital facet of industrial operations.

Following Teddlie and Yu's explanation, the participant pool size in purposive sampling typically remains small, often 30 or fewer, depending on the specific selection criteria. In contrast, probability sampling necessitates a larger participant pool, usually consisting of at least 50 individuals, to ensure representativeness (Teddlie & Yu, 2007). Given our need to limit the participant group through the required expertise, achieving a higher participant count might still seem challenging, even though the survey participants are global. In order to maintain the study's relevance, the objective is to collect responses from a minimum of 50 participants using the online questionnaire.

Finding a sufficient number of attendees for a quantitative preliminary survey with such a professionally limited group of participants is not trivial. Optimally, the participants should be approached personally or contacted by e-mail to obtain the necessary filtering and a reasonable response rate. Salganik and Heckathorn highlight the importance of following standard sampling and estimation procedures, requiring researchers to select sample members with a known probability of inclusion. Typically, this requirement hinges on the availability of a sampling frame, essentially a comprehensive list of all individuals within the population under study. However, in cases where a researcher aims to investigate a population lacking a readily accessible sampling frame, the task may involve attempting to establish such a frame (Salganik & Heckathorn, 2004).

Nonetheless, this endeavor proves to be either impractical or unfeasible for specific populations. This is primarily due to two factors: the diminutive size of the target population and the inherent challenges associated with locating its members. Another obstacle may arise from the difficulty in distinguishing individuals from the target population from those belonging to the general population. These unique and intricate scenarios are characterized as "hidden populations," where conventional sampling and estimation techniques cannot be applied. This term encompasses those groups whose study presents exceptional complexities that necessitate innovative research approaches beyond the scope of standard methodologies (*ibid.*). The term hidden or hard-to-reach groups can refer to stigmatized groups but equally to elite groups (Atkinson & Flint, 2001). This also applies to the present work.

The snowball method was deemed the most suitable for participant selection, as it is particularly effective when accessing hard-to-reach individuals (Stockemer, 2019). This method, among others, is one of the most commonly used non-probability sampling techniques (*ibid.*). Brosius, Haas, and Koschel describe this method as basically a combination of a purposive and a random selection method, which in some instances is justified by the object of investigation or even represents the only possible method for selection. This is because, in the case of new objects of investigation, one is often challenged that neither the entire population nor a subgroup to be deliberately selected is precisely known (Brosius et al., 2016). Przyborski and Wohlrab-Sahr describe that the snowball method is used to explore a specialist area and identify essential players within this area. However, there is a

risk of limiting oneself to specific network structures and viewing the field exclusively from their perspective. Nevertheless, if it is possible to counteract this risk, snowballing can provide a helpful approach to capturing the internal structure and contrasts within the field (Przyborski & Wohlrab-Sahr, 2014). Similar problems with the sample selection of hard-to-reach populations were encountered during their research work, for example, by Schlepphorst, Koetter, Werner, Soost, and Moog (Schlepphorst et al., 2020), Bailey (Bailey, 2019) or Hauser, Simonyan and Werner (Hauser et al., 2021) or Skordaki and Bainbridge (Skordaki & Bainbridge, 2018) or Nilchian, Majrouhi Sardroud, Darabpour and Tavousi Tafreshi (Nilchian et al., 2022) or Olawumi and Chan (Olawumi & Chan, 2021) to name a few who also successfully applied the snowball sampling method.

To achieve this objective, a selection of sources was made, including contacts from the industry, contacts associated with professional institutions, individuals within reliability networks, and contacts with university affiliations.

An international network of experts exists, particularly in industrial maintenance and reliability engineering, to which the author has access. Twenty-one international professional institutions and networks in industrial maintenance, general engineering, and reliability engineering were contacted and asked to distribute the survey link to appropriate members. The response from these institutions and networks varied widely, from no response to immediate support. In addition, contacts at universities (especially at FOM University, Germany, and Niederrhein University, Germany) were asked to participate in the survey or to distribute the link to suitable participants. The online survey respondents were asked to forward the survey to professionals with comparable expertise.

Even though the group is exceptionally homogeneous in terms of expertise, due to the various methods and procedures used to recruit participants, it was assumed that a diverse group with different professional backgrounds and geographic origins would participate in the survey, which helps to avoid biased responses to the questions posed.

3.2 TOOLS FOR PRELIMINARY STUDY

The literature review conducted in this study revealed limitations in the existing research. In particular, it became apparent that several fundamental data

critical to the research topic were conspicuously absent, as presented in Chapter 2.2 - State of Research. These notable omissions resulted in gaps in the existing knowledge base that required proactive attention. To address these data gaps and enhance knowledge in this field, an online questionnaire was designed as a research tool. A deliberate approach was taken to address these gaps when creating this questionnaire. The questions included in the questionnaire were carefully worded to gather information on the missing data explicitly identified. It serves as a way to collect relevant information directly from individuals or sources with the necessary knowledge or experience related to the research topic. By designing the questionnaire to address identified gaps, this research seeks to enhance understanding of the topic and generate valuable data for further analysis and discussion. A total of 26 questions were defined for this purpose. These are composed of one question for free text entry, eleven open questions for entering numerical values, and 14 closed questions. It was allowed to enter an additional free text for seven questions under "others." The survey requires the input of numerical values. Therefore, the pure application of closed questions was not possible. Equally, the individual circumstances of the respective companies must be considered. The situation is similar here. These aspects cannot be adequately addressed with completely closed questions.

In order to formulate the questions appropriately and precisely on a scientific basis, the "10 commandments" of question formulation described by Porst were applied (Porst, 2000, 2019). The keywords from this can be found in Appendix 8.1. Furthermore, the established scientific guidelines for questionnaires, according to Porst, Kirchhoff et al. and other standard works, were adhered to (Kirchhoff et al., 2010; Porst, 1998, 2000, 2014, 2019; Schöneck & Voß, 2013).

The literature offers various approaches to determining an appropriate number of questions for a questionnaire, but concrete guidelines remain scarce (Bortz & Döring, 2006). For example, Sharma states that a good questionnaire can contain between 25 and 30 questions (Sharma, 2022). To prevent participant disengagement and response bias, efforts were made to keep the questionnaire at a reasonable length (Brandt & Moosbrugger, 2020). However, the number of questions was chosen so that the relevant points could be answered. Chapter 3.3.3 - Determination of Questions for Preliminary Study describes the selection of questions in terms of content.

The website "UmfrageOnline.com" offers a web-based tool for creating electronic interview forms. The desired question types can be set with the respective selection options. The planned average processing time was ten minutes at most. It was possible to interrupt the survey and continue it later. For reasons of analyzability, the participants could not skip any questions. If they could not answer a question accurately, the participants were encouraged to estimate as precisely as possible. The entire questionnaire can be found in Appendix 8.3.

Before the actual survey was carried out, a pre-test was performed. Pretests are essential in quantitative surveys, in contrast to qualitative interviews, since the questionnaire and survey design cannot be changed after the launch. Otherwise, standardization could be jeopardized (Weichbold, 2019). Porst and Stockemer both assert that conducting a pretest is widely regarded as an essential step in the successful development of a questionnaire. (Porst, 2014; Stockemer, 2019). Accordingly, a pretest was conducted prior to making the survey publicly available. Porst explains further that even for executing a "classical pretest," there are no binding or generally accepted rules. However, every social science methods textbook contains a chapter on "pretesting," which, in comparison with each other, is highly different, and sometimes contradictory recommendations are given regarding the execution of a pretest (Porst, 1998).

The pretest conducted for the preliminary study played a crucial role in assessing several critical aspects related to the study's questionnaire. Its main objective was to verify the reliability and effectiveness of the survey instrument through a thorough evaluation of its various components. Firstly, the pretest aimed to gauge the comprehensibility of the questions posed in the questionnaire. This involved evaluating whether the language and phrasing of the questions were clear and easily understandable to the intended respondents. It was essential to ensure that participants could grasp the intended meaning of each question. Another critical aspect addressed by the pretest was the sequencing of the questions. Proper sequencing is essential in a questionnaire to maintain the survey's logical flow and prevent confusion or bias in responses. Through the pretest, it was possible to identify issues with the questions' order and make necessary adjustments to enhance the survey's coherence. Technical problems were also an important focus of the pretest. This involved checking for any technical glitches or errors that might arise during the survey administration.

In addition to technical issues, the pretest scrutinized the questionnaire for spelling mistakes or typographical errors. Such errors can undermine the professionalism of the survey and distract interviewees, potentially affecting the quality of their responses. Lastly, the pretest assessed the duration of the test. This involved estimating how long it took respondents to complete the questionnaire. It was essential to balance collecting comprehensive data and not overburdening participants with a lengthy survey. The questionnaire's length could be adjusted based on the feedback and timing data gathered during the pretest.

Five people performed the pretest. Porst points out that if specific target groups are being surveyed, it will be evident that the test candidates belong to these particular groups (Porst, 2014). All participants are engineers who have worked in reliability engineering or general maintenance for several years. A strong connection to the survey subject can be assumed. The testers work in two European countries and three different types of industries. The results must also be applied as an instrument for quality control and improvement. Thus, questions may be re-phrased or answer categories changed (Weichbold, 2019).

As a result of the pretest, minor errors were found. These include one error in the flow and two minor typos. Those were improved before the start of the survey. The average completion time for the online survey in the pretest was eight minutes.

The data obtained in this study was analyzed using the computer program SPSS, specifically IBM SPSS Statistics version 27. This software, developed by IBM, Ehningen, Germany, is a widely recognized and powerful tool for statistical analysis. SPSS was chosen as the preferred software for data analysis due to its versatility and robust capabilities in handling various statistical procedures.

3.3 REALIZATION OF PRELIMINARY STUDY

3.3.1 Quality Criteria

Quality criteria must be observed for all quantitative research data collection and analysis steps. This way, the data can be collected, and the results can be evaluated as error-free as possible (Krebs & Menold, 2019). The quality of a questionnaire can be determined by three main criteria:

- objectivity,
- reliability, and
- validity (Bortz & Döring, 2006).

In order to fulfill these criteria as well as possible, the usual guidelines for scientific questionnaires were followed when creating the questionnaire. Please also refer to Chapter 3.2 - Tools for Preliminary Study.

Moosbrugger and Kelava specify that a test is considered objective if the entire procedure, including the test materials, presentation, scoring, and interpretation rules, is so precisely defined that the test can be conducted independently of the location, time, test administrator, and scorer. The same result and the same interpretation of the result should nevertheless be achieved for a specific test subject with regard to the examined characteristic (Moosbrugger & Kelava, 2020). Bortz and Döring state that objectivity is generally a relatively unproblematic test quality criterion that is easy to achieve even with self-constructed questionnaires or tests (Bortz & Döring, 2006). Within the scope of this research, the objectivity of implementation can be regarded as ensured. All implementation conditions are standardized. Since the survey is conducted online, any form of interaction with the test administrator is precluded. The instructions are uniform for all participants and are accessible on the brief introductory page of the online questionnaire.

Additionally, identical questions were posed to all test subjects. It is reasonable to infer that the test outcome hinges solely on the attributes of the test individual and not on additional factors. While the absolute objectivity of implementation is consistently sought after, attaining it in reality may not always be possible (Moosbrugger & Kelava, 2020). According to Moosbrugger and Kelava, the evaluation objectivity of the individual test items in multiple-choice tests is generally achieved without any problems (*ibid.*). All other questions with free input (here, predominantly numerical values) were evaluated without exception according to the same predefined procedure. The results were processed using IBM SPSS Statistics 27 software according to the exact specifications. Consequently, the test evaluator does not influence the assessment, ensuring evaluation objectivity in the evaluation process.

In summary, the research ensures the objectivity of test implementation and evaluation by maintaining standardized conditions, consistent instructions, and uniform evaluation procedures.

The reliability of a measurement refers to the extent to which repeated assessments of a specific item yield consistent results (Brühl & Buch, 2006; Krebs & Menold, 2019). It is essential to recognize that a lack of objectivity can impact reliability, as variations among test users introduce error variance. Consequently, reliability is constrained by the degree of objectivity (Bortz & Döring, 2006). Reliability is secured if the same results can be generated in a possibly repeated measurement as in the first measurement. If this is independent of the researcher, repeatability is expected (Schöneck & Voß, 2013). However, it should be perceived that perfect reliability is unrealistic in practice, as errors due to situational interference, respondent fatigue, misunderstandings, or assumptions cannot be completely ruled out (Bortz & Döring, 2006).

In this preliminary study, the reliability of the survey can not be determined by measurements, as the experts surveyed were not available for further testing, such as retesting, due to strict confidentiality. In addition, the considerable differences between the companies in the sample of experts lead to a high variance in other measurement methods, such as test-retest reliability. Due to these expected differences, a measurement method would not be very meaningful, as the companies surveyed were deliberately selected to be diverse. It is expected that an unavoidable variance and possible measurement errors, such as the estimation of numerical values, will not have a detrimental effect on the study conducted, which is primarily concerned with identifying trends in the various companies. However, given its independent and standardized format, the survey is expected to yield similar results if repeated with the same participants.

The main criterion for all quality criteria is validity. It should provide information on whether the test measures what is intended to be measured (Brühl & Buch, 2006). Three main types of validity can be distinguished: Content validity, criterion validity, and construct validity (Bortz & Döring, 2006). Schöneck and Voß state that validity is secured when the indicators or variables can capture what is to be captured (Schöneck & Voß, 2013). Although high validity requires high

objectivity and reliability, these two characteristics alone are not sufficient to ensure high validity (Moosbrugger & Kelava, 2020).

Bortz and Döring point out that assessing and ensuring the validity of a test requires considerably more effort than objectivity and reliability (Bortz & Döring, 2006). Krebs and Menold emphasize that an auxiliary theory is essential for ensuring the validity of a measurement instrument. This theory should cover the attitude object, the various dimensions (facets), and the possible relationships (correlations) between the facets. This approach ensures that the measurement instrument adequately reflects the complexity and that the attitude under consideration is not too narrowly defined. The validation of a measurement instrument is, therefore, a comprehensive research task that aims to examine the statements of an auxiliary theory. Various methods that relate to different concepts or forms of validity can be applied and combined (Krebs & Menold, 2019).

In this preliminary study, content validity — also referred to as face validity — can be assessed. This type of validity is established when the test items fully encompass the key aspects of the construct being measured. A test's content validity level cannot be determined by numerical measures but is solely based on subjective assessments (Bortz & Döring, 2006).

When creating the questions (for a detailed description, see sub-chapter 3.3.3 - Determination of Questions for Preliminary Study), the well-known guidelines for creating questionnaires were followed precisely to ensure content validity.

Criterion-related validity describes the degree of similarity between the results of a test measurement and one or more external references (criteria). This similarity is usually measured by their correlation (Bortz & Döring, 2006; Drost, 2011).

The difficulty with this form of validity is that this preliminary study is a descriptive study; therefore, there are no reliable external criteria for further investigations. Rather, this survey is intended to create a data basis in the first step. Bortz and Döring point out that finding a suitable external criterion is often tricky. In addition to the challenge of identifying a suitable external criterion in the first place, the question arises as to how this criterion can be operationalized. If the criterion values are recorded invalidly or unreliably, any validation with this criterion is obviously not usable. They also mention that an external criterion, if a valid one exists,

is often an observable event that can only be measured at a later point in time (Bortz & Döring, 2006).

Construct validity is the third type of validity. A test is considered to have construct validity if hypotheses can be derived for the target construct to be measured, which can be confirmed by the test results (Bortz & Döring, 2006). They further explain that the successful validation of a construct is only possible if, in addition to the test or questionnaire to be assessed, only reliable instruments are used, and the hypotheses tested are valid (Bortz & Döring, 2006; Brühl & Buch, 2006). As mentioned previously, this preliminary study is an exploratory study to generate basic data. Tested hypotheses are therefore not available. Instead, the aim of the main study is to generate such hypotheses.

3.3.2 Data Collection and Analysis

In this research project, the utmost importance was placed on ensuring strict confidentiality and anonymity for all participants. This commitment to confidentiality was explicitly emphasized throughout the study. As Bos highlighted, it is an inherent and self-evident principle that the results obtained from this research would only be utilized for scientific purposes (Bos, 2020). This commitment to confidentiality was reiterated on the introductory page of the online survey to assure participants of the secure handling of their data.

The data was collected through an online questionnaire hosted on the "UmfrageOnline.com" platform. This questionnaire was made accessible for participation from April 20, 2021, through June 19, 2021, allowing for a substantial data collection window. The online questionnaire was equipped with error-prevention mechanisms to maintain data quality and integrity. For instance, it was designed to prohibit text entry in fields intended for numerical values. While these preventive measures substantially reduced the potential for errors, it was acknowledged that some might still occur (Van den Broeck et al., 2005). All data collected was subjected to thorough scrutiny for validity, accuracy, and completeness. Importantly, any misspellings in open-text entry fields were left unaltered.

The data cleansing process adhered to the methodology described by Van den Broeck, Cunningham, Eeckels, and Herbst (Van den Broeck et al., 2005).

Notably, the data quality was deemed excellent overall, and data cleaning was only necessary in a limited number of cases where implausible data points were identified.

Missing data (non-response) indicates the absence of one or more values within a dataset (Bannon, 2015). The issue of missing data values is a challenge that most data sets in the social sciences face (Spieß, 2010). Raaijmakers states that incomplete data poses a frequent challenge in empirical investigations, particularly in survey-based studies (Raaijmakers, 1999). In surveys in the area of social sciences, it is often unavoidable that interviewees indicate "don't know" or refuse to answer specific questions (Bergmann & Franzese, 2020). In this work, missing values were dealt with as follows. Firstly, it is important to distinguish between a complete refusal to participate in the survey (unit-non-response) and a refusal to answer specific questions (item-non-response) (Jensen, 2012; Spieß, 2010). A unit-non-response in the actual sense could not occur in the present preliminary survey, as it was anonymized as a whole. Therefore, the actual participation of individuals in the survey cannot be verified. As already described in the relevant section, it was primarily groups of people suitable for the subject who were approached and asked to participate, but not individuals.

However, more attention must be paid to item-non-response. The online survey was designed so that participants could not skip individual questions but had to answer them or abandon the survey. Although it was possible to enter implausible values to a limited extent, these options were checked by the online platform and prevented where possible. For example, entering letters in fields intended for numerical entries was impossible, as described before. A check of the data did not reveal any nonsensical values.

Question 8, "Is your organization planning to establish a separate reliability engineering department?" was explicitly designed to exclude participants who were neither planning to establish a RED nor wishing to introduce one. This question was only asked of participants who had indicated in the previous question that they were not currently operating a RED. For all participants who indicated "no" here, the survey ended intentionally at this point. Therefore, the number of survey participants was deliberately reduced by 13 at this stage.

All other questions did not result in exclusion from the survey and could only be exited at the participant's discretion. Participants always had the option to withdraw from the survey voluntarily. Consequently, this ensures no direct omissions in individual participants' responses. Instead, once a participant chose to withdraw, they could no longer answer any subsequent questions.

Ten participants stopped the survey after answering the first two questions (current occupation and origin). The responses of these participants were not included in the data analysis.

While answering the questions, five participants left the survey on their own. In the subject-specific literature, several methods deal with such missing values (Bergmann & Franzese, 2020). Engel and Schmidt specify that there are two general approaches. On the one hand, cases with missing values can be excluded from statistical calculations, or the missing values can be replaced by plausible values in terms of content (Engel & Schmidt, 2019). There are several different approaches in the literature for replacing missing data (Bannon, 2015; Bergmann & Franzese, 2020; Enders, 2010).

Due to the number of available data sets, it was decided not to impute the missing data but to evaluate only the complete data. This was to avoid any distortion of the data, as any replacement procedure has the potential to do so.

On completion of data collection and cleaning, the survey data underwent a coding phase to facilitate further analysis. The coding process followed the guidelines described by Bryman (Bryman, 2016). In this process, each non-numeric value label was systematically assigned a numeric value, an essential step for subsequent data interpretation. This assignment step was unnecessary for value labels already recorded numerically.

To ensure transparency, the numerical values assigned during coding are documented in the codebook, which can be found in Appendix 8.4. This comprehensive document serves as a guide detailing the conversion of the non-numeric designations into the corresponding numeric representations.

The purpose of carrying out this careful coding process was to ensure that the data was ready for thorough statistical analysis. The analysis itself was conducted using the IBM SPSS Statistics 27 program.

3.3.3 Determination of Questions for Preliminary Study

The questions posed in the preliminary study are based on comprehensive and in-depth considerations resulting from the gaps in the literature analysis. In order to close the gaps in the literature research and broaden the general database, the questions in the online survey were divided into four thematic areas. The questions deliberately go beyond merely closing gaps to create a solid data basis.

a) Basics and overall organization (questions 1-8)

The first question aims to establish the qualifications of the participants. This is essential to ensure that survey participants possess the required professional background to provide well-informed responses to the subsequent questions. The second question seeks to determine the geographical distribution of the participants. This is vital as the survey seeks to achieve the broadest possible geographical coverage. It allows the inclusion of diverse perspectives and experiences in the survey. The following three questions focus on organizational aspects. The third question aims to determine the size of each location. Thus, understanding the differences among the participating facilities is crucial. The fourth question explicitly addresses the size of the maintenance department. The fifth question determines the ratio of the RED's size to the organization's maintenance size. The sixth question focuses on the academic qualifications of the RED employees. This is relevant to understanding the technical expertise of the team. The seventh and eighth questions aim to gather information about the existence or planned introduction of a RED at the respective locations. These questions are important to understand whether the RED is already active or planned for the future.

Overall, this block of questions aims to close knowledge gaps on the qualifications, organizational structures, and plans related to the RED in the participating facilities.

b) Organization and tasks of the reliability departments (questions 9-17)

This block of questions is about collecting more detailed information about the organization and tasks of a RED. The questions aim to gain a deeper understanding of the structure and function of this department.

The first two questions (nine and ten) aim to clarify the organizational affiliation of the RED within the overall structure of the company. The respective reporting line is also asked to understand which hierarchical levels the RED reports to. This is crucial to understand the responsibilities and integration of the RED into the overall organization. Question eleven aims to identify the maintenance strategy of the RED. Subsequently, the questions ask about independence in the implementation of projects. The aim is to determine to what extent the RED can act independently or whether coordination and approval from other departments or bodies is required to carry out projects. Question 13 allows participants to give their opinion on whether they consider the organization of the RED to be useful. It provides an opportunity to obtain feedback and assessments regarding the effectiveness of the RED within the overall organization. Participants are also asked to share their ideas about the organization of the RED. This serves to collect ideas for an optimal design of the department. The following two questions aim to determine whether RED employees work exclusively for this department or whether they also perform other activities within the organization. If so, respondents are asked about the proportion of other activities. Finally, question 17 inquires about the specific tasks performed by the respective RED, providing a clear overview of their operational roles and responsibilities within the organization. In summary, this block of questions is primarily aimed at closing the knowledge gaps regarding the integration of a RED into the organization, the respective maintenance strategy, whether the employees of a RED perform their tasks full-time, which activities are mainly carried out and the degree of independence in the respective RED of the participants.

c) Budget of reliability engineering departments (questions 18–20)

In this specific thematic section, the primary objective is to gather essential information about the RED and its financial aspects within participating companies. The focus here revolves around three critical aspects of the effectiveness and impact of the RED in promoting resource efficiency and cost savings. Firstly, one of the central queries centers on whether the RED operates with an independent budget explicitly allocated for improvement measures. Understanding whether the RED has dedicated financial resources to enhance resource efficiency is crucial, as it can signify a commitment to addressing sustainability and resource optimization.

Secondly, it is imperative to determine the proportion of the maintenance budget these companies allocate to reliability measures. This question seeks to gauge the significance of resource reliability in their budgetary planning. Lastly, the survey delves into whether the operation of the RED has already led to tangible cost savings in the participating companies. This question is pivotal, as it helps gauge the real-world impact of the RED. If the RED has indeed resulted in cost savings, it underscores the effectiveness of the directive in promoting resource efficiency and its potential to deliver financial benefits.

Collectively, these questions are designed to bridge gaps in knowledge about the budgetary aspects of the RED and its role in realizing savings within participating companies. The responses to these questions will provide insights into the financial dimensions of resource efficiency initiatives and whether the RED contributes to sustainable and cost-effective operations in these organizations.

d) Expected savings and goals of reliability engineering departments (questions 21–26)

This final section of the preliminary study is primarily concerned with assessing the expected and achieved targets of a RED in three critical areas: reducing production losses, reducing maintenance costs, and extending plant uptime. The years 2019 and 2020 are examined as a reference point. However, it also looks at expectations for future reductions in these areas. In addition, the use of KPIs and their role in monitoring and managing these initiatives are analyzed.

First, it was asked whether the respective REDs have successfully achieved their goals in terms of reducing production losses, minimizing maintenance costs, and extending operating time. This analysis serves as an important benchmark for evaluating the overall effectiveness of the REDs. Similarly, it is vital to identify expectations for the future at the various sites involved in the study. Additionally, the study aims to address gaps related to the KPIs used in these REDs. A thorough understanding of these key performance indicators is crucial as it will enable improvements to be made and monitored based on data-driven insights.

Essentially, this final section of the research fills in knowledge gaps to assess the performance of the RED and learn the future expectations of the participating companies.

3.4 DETAILED FINDINGS

A total of 76 people responded to the survey. Unfortunately, not all respondents completed the survey until the end. During the survey, 13 participants indicated that they did not have a RED and had no plans to establish one. For these participants, the survey ended with this question. It can be assumed that these respondents could not answer the remaining questions appropriately. Furthermore, only fully completed datasets were considered from the outset.

The questions were divided into four sections, as described in the previous sub-chapter. This division was not visible to the participants. The results are presented in the order of these sections. The findings were analyzed and presented using descriptive statistical methods. For each question's findings, careful consideration was given to whether a visual representation, such as a graph or table, would enhance understanding. The chosen presentation format does not indicate the significance of the findings.

3.4.1 Section 1 – Basics and Overall Organization

In this section, participants were asked about their professional background, origin, company, and department size. They were also asked whether the company already had a RED or planned to start one.

Question 1: You are active as?

The data presented in Figure 16 via a pie chart reveals that most survey participants have direct affiliations with reliability engineering (49.2%) or maintenance management (27.9%). Nevertheless, it is worth noting that individuals with expertise and leadership roles outside of these professional domains also made essential contributions, accounting for 22.9% of the respondents.

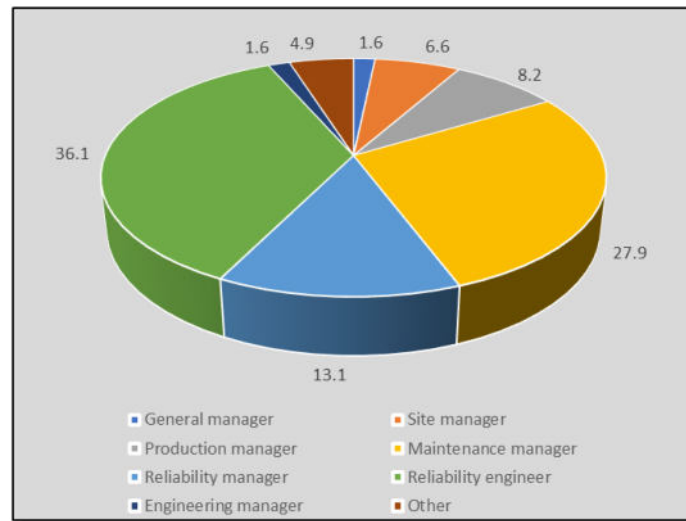


Figure 16: Participating occupational groups [%]

The entries in the "other" field included individuals with backgrounds such as a maintenance and engineering manager, a consultant, and a sales technician. This diverse representation of participants was intended to ensure that individuals with relevant expertise could address the questions from multiple perspectives.

Question 2: In which country is your site?

The graph (Fig. 17) shows that people from all around the globe responded to the survey. The majority of participants came from European countries (67.2%). Unfortunately, there were no participants from South America.

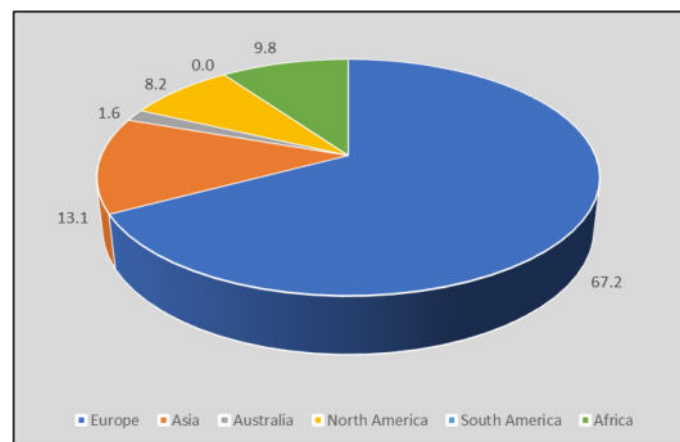


Figure 17: Origin of participants by continent [%]

Nevertheless, achieving an international mix of participants made it possible to get a global view of the survey questions.

Question 3: Number of employees at your site?

The chart (Fig. 18) shows the number of employees at each participant's site. When considering all the locations taking part, the average number of staff employed was 717.1. It was stated that the biggest site employed 5,000 staff. In comparison, the smallest location taking part had 52 people in its workforce. The majority of the companies (73.8%) are clearly attributed to large companies (>250 employees) (European Commission – Eurostat, 2021). Medium-sized companies are also represented, with 16 participants (26.2%). Small businesses (<50 employees) were not considered.

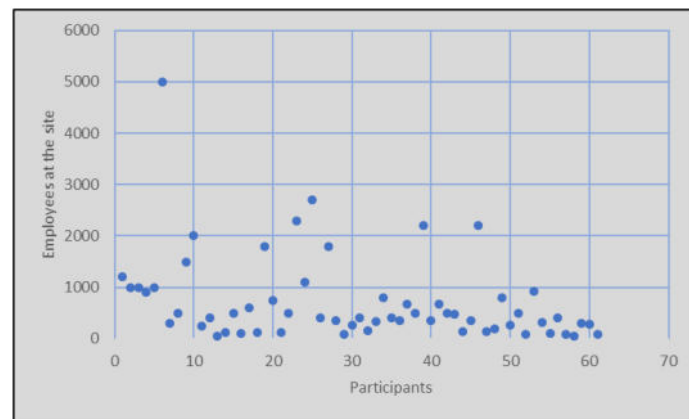


Figure 18: Employees at the site

Thus, the objective was achieved not only by surveying employees of large companies but also by capturing the views of medium-sized enterprises.

Question 4: How many of them work in maintenance?

The number of maintenance employees at each location is shown here (Fig. 19). All sites had maintenance employees at the time of the survey. The mean value was 113.6 personnel in this field. A wide range is shown, from four employees (three times) to a maximum of 750 employees.

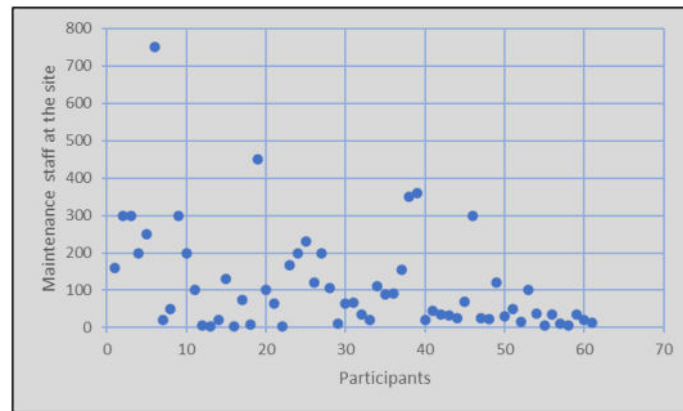


Figure 19: Maintenance staff at the site

This fact also shows that the participants' professional experience varies greatly due to the different sizes of the maintenance departments, and therefore, different perspectives can be brought into the survey.

Question 5: How many of them work in the area of reliability engineering?

The table (Tab. 1) shows the number of employees in each RED. A wide range is shown here. While six participants stated that they currently have no employees in the area of reliability, one participant stated that 50 people work in this area in his company. However, most companies employ five or fewer people in this field (55.7%). Eleven companies employ only one person in the field of reliability engineering (18%).

Table 1: Number of employees in the RED

Number of staff	Quantity	In %
0	6	9.8
1	11	18.0
2	11	18.0
3	6	9.8
4	2	3.3
5	4	6.6
6	4	6.6
8	3	4.9
9	1	1.6
10	4	6.6
11	1	1.6
20	2	3.3
25	1	1.6
30	3	4.9
40	1	1.6
50	1	1.6

This also indicates that the participants come from diverse and somewhat differently structured companies. Therefore, it can be assumed that the study reflects a range of perspectives and experiences.

Question 6: How many of the employees in reliability engineering have a university degree?

In response to the question, six participants indicated that they presently do not employ any personnel specializing in reliability engineering; consequently, none possess a university degree in this field. Analysis of companies currently employing staff in reliability engineering departments (RED) reveals that 90.9% of surveyed companies have employees with university degrees. A detailed examination of various companies illustrates a highly diverse scenario. For instance, in 25 companies with a RED, all employees hold university degrees (45.5%), while in other companies, none of the employees possess such qualifications (9.1%). This underscores that the majority of companies opt for highly qualified personnel within the realm of reliability engineering.

Question 7: Does your site have its own reliability engineering department?

For this question, 40 respondents (65.6%) indicated that they had a RED at their site, as shown in Figure 20. Consequently, 21 respondents (34.4%) reported that they did not have this department at the time of the survey. Thus, most participants already operate a RED and can answer the questions from this perspective.

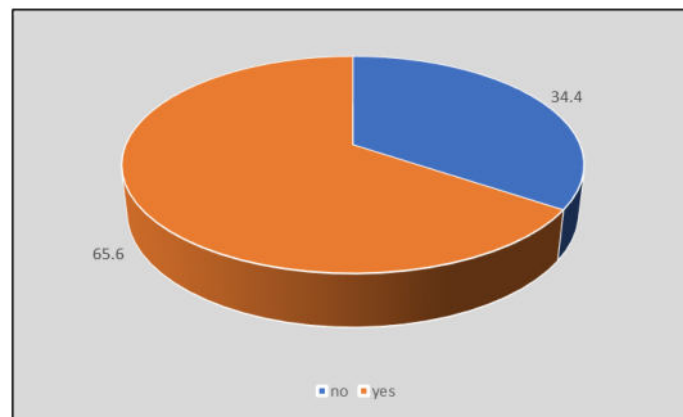


Figure 20: Own RED? [%]

Question 8: Is your organization planning to establish a separate reliability engineering department?

Just the 21 participants who answered in the previous question that they do not currently have a RED were asked this question. Of these, eight participants (38.1%) responded that their organization plans to start a RED, whereas 13 participants (61.9%) indicated that they do not (Fig. 21). For these participants, the survey ended here, as it could not be assumed that the following questions would be answered meaningfully.

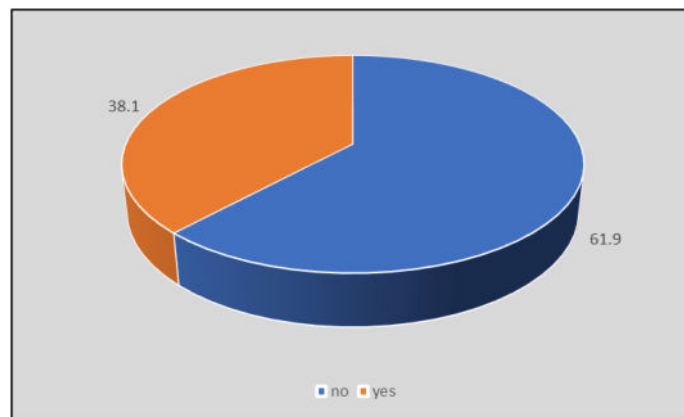


Figure 21: Establishing a RED? [%]

3.4.2 Section 2 – Organization and Tasks of Reliability Engineering Departments

In the questions in this section, the participants were mainly asked about the organizational integration of the RED in the company, the RED's tasks, their time approach, and their organizational freedom.

Question 9: To which department does reliability engineering belong?

Participants described different ways of integrating the RED into the existing organization. However, in most cases (75%), the RED is incorporated within the standard maintenance department. All other areas are much less well represented here (Fig. 22). An affiliation to production or directly to the site manager was also specified. Also indicated was that a RED can also be interdepartmental. Others indicated that this department belongs to engineering (4 times, 8.3%). One participant indicated that he did not know.

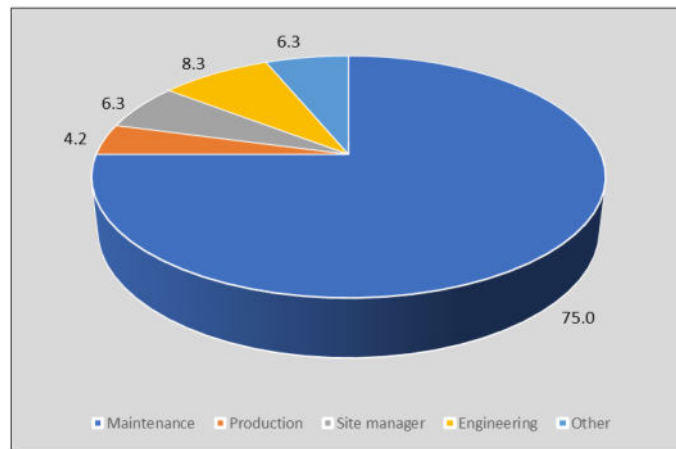


Figure 22: Organizational allocation of the RED [%]

This form of organization shows that the "classic" organization of the RED within maintenance is predominant, but other ways can also result from the company's organization.

Question 10: To whom does the head of reliability engineering report?

Following the answers to the previous question, the diagram (Fig. 23) shows that most RED managers report to the maintenance manager (58.3%). In some sites, they also report to the site manager (22.9%). Occasionally, it is reported to the engineering manager (8.3%). In some instances, they report directly to the general manager. One participant stated that he reports to global engineering and another to the maintenance and engineering manager. A direct reporting chain to the production manager did not emerge.

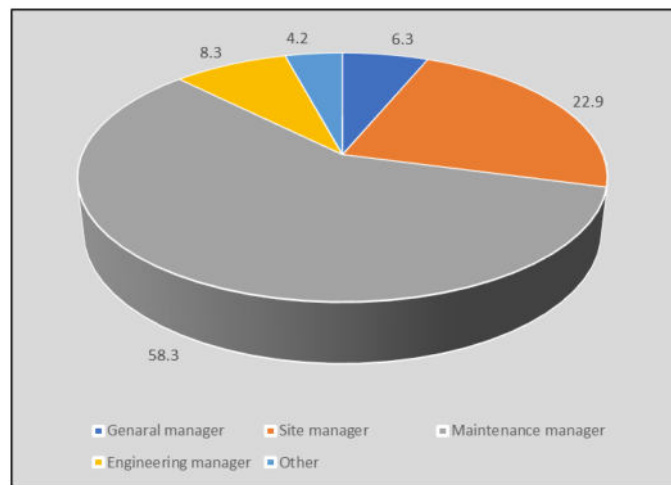


Figure 23: Reporting line of the RED [%]

Building on the responses to the previous question, the "classic" reporting structure within maintenance is evident here as well. However, it is also clear that direct reporting to production management is uncommon. Furthermore, it turns out that the head of the RED reports directly to a higher executive, such as the site manager or even the general manager, in nearly 30% of the companies. This reporting path shows the high value of the RED within the company.

Question 11: Which maintenance strategy is pursued?

A purely reactive strategy is only rarely used. Only one participant stated that his company worked solely reactively. Nevertheless, a total of 20.8% of participants stated that they worked reactively to some extent. Preventive (64.6%) and predictive (52.1%) work are predominant. Some manufacturing companies use multiple strategies (Fig. 24).

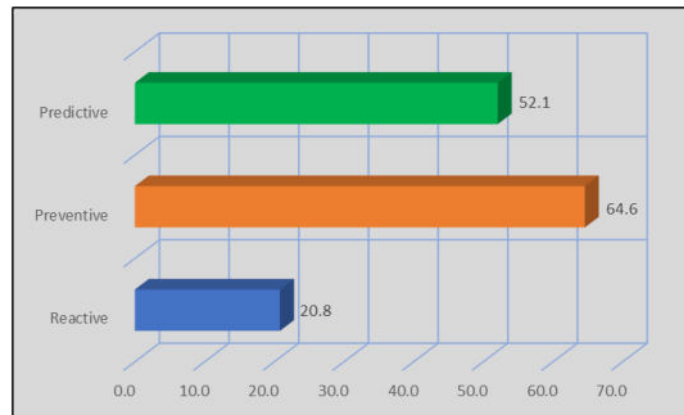


Figure 24: General maintenance strategies (multiple answers possible) [%]

These results indicate that a single strategy is often inadequate for all assets. As a result, a combination of different strategies is implemented (with a total of >100% as a result).

Question 12: Can reliability engineering implement savings projects on its own, or does it need the approval of a manager (e.g., asset manager, plant manager, etc.)?

It was presented that many REDs carry out their own projects (47.9%), i.e., without the consent of a higher management level, to some extent at least (39.6%). Only 12.5% of REDs may not (Fig. 25).

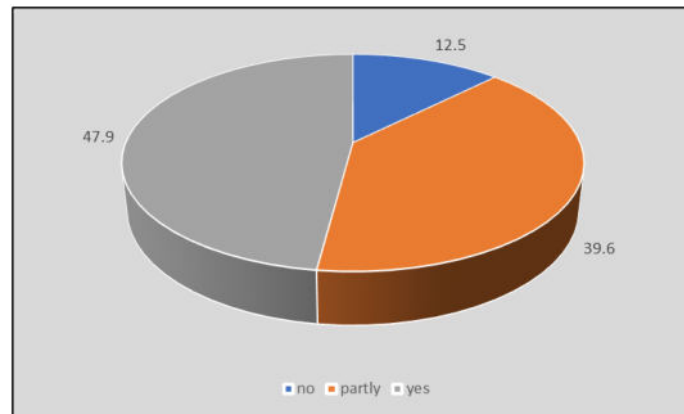


Figure 25: Realization of own reliability projects [%]

This opportunity reflects the great trust that the managers place in their specific REDs.

Question 13: From your experience, is this organization purposeful and reasonable?

For the majority of respondents (83.3%), the organization in their company was purposeful and reasonable at the time of the survey (Fig. 26).

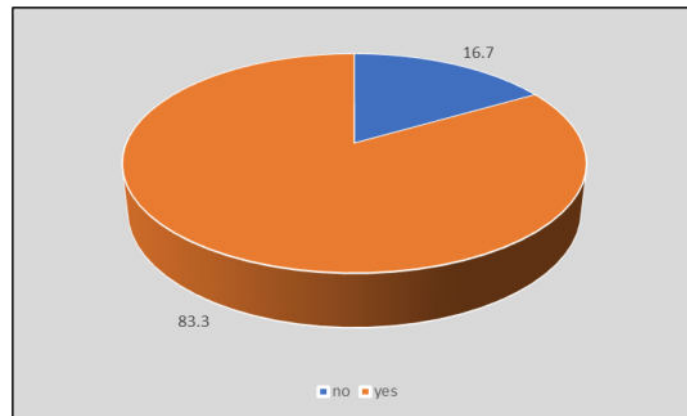


Figure 26: Organization purposeful? [%]

It can be deduced from this that the processes mainly worked well during the period surveyed.

Question 14: From your perspective, what should the reliability engineering organization look like?

The evaluation of the responses revealed a somewhat mixed picture here. Only four participants expressed satisfaction with their current situation, with one noting that they at present report to the maintenance manager. Four participants indicated that the RED needs to be part of maintenance and thus should report to the maintenance manager. However, some participants suggested that the RED should report to production management, while others argued that it should remain independent and report directly to the site or general manager. One participant noted that the RED should be part of a centralized, multi-site team. A close collaboration between production, maintenance, and RED was also desired. Eight participants also stated that the RED must have its own budget and/or be allowed to implement its own projects. Several participants also said that the RED needs more staff. In particular, specialists from several technical disciplines are also needed. One participant stated that the RED should make up 10% of the maintenance staff. It was also mentioned that the RED must have a good database, a core

team that defines methods and tools, and dedicated personnel for condition monitoring tasks. It was also suggested that the focus should be on bad actors and low MTBF. Also, a clear strategy needs to be developed; it follows that the RED must be independent of other work.

In the statements given here, it is apparent that the focus of the respective participants and companies varies greatly. Most participants tend to favor the approach of integrating the RED into maintenance. Nevertheless, some tendencies aim for the RED to be a completely independent department with a reporting line to the chief executive. This also results in the desire for an independently managed budget and personal responsibility for projects. Some of the REDs appear to be understaffed.

Question 15: Do the employees in reliability engineering deal exclusively with plant improvement topics, or do they also take on other tasks?

The answers to this question show that almost 71% of people working in reliability engineering do so full-time (Fig. 27).

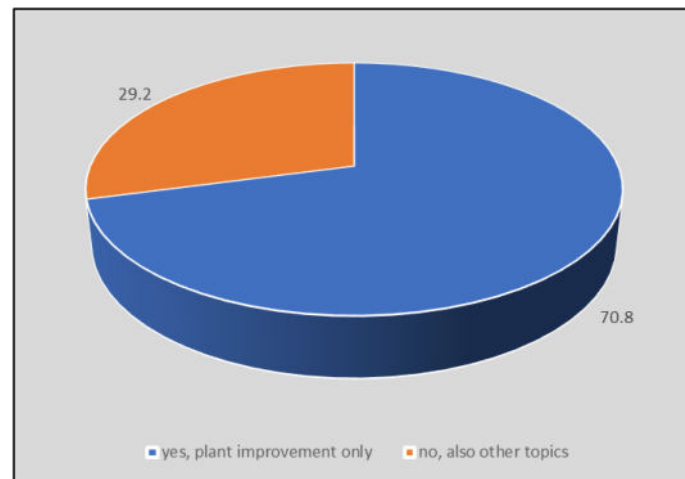


Figure 27: Does the RED deal exclusively with plant improvement? [%]

Even if most RED employees do not perform any other activities, there is still a relevant proportion of nearly 30% of employees who are also involved in other tasks.

Question 16: Which proportion of time is spent on other activities?

This question was only asked to participants who indicated that staff at the RED were not exclusively involved there. These 14 participants stated that, on average, 35.7% of their working time was spent on activities other than reliability engineering (Fig. 28). However, concerning the respective company, there is a noteworthy difference of 20% to 90% for other tasks.

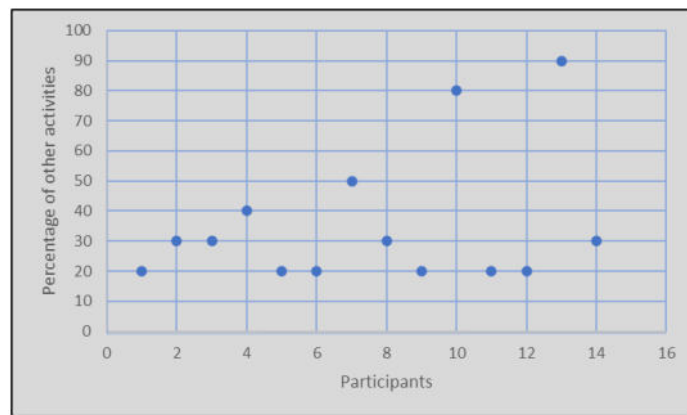


Figure 28: Percentage of other activities [%]

This suggests that even in companies where RED employees do not work full-time in reliability engineering, they still dedicate nearly two-thirds of their working time to it. A strong emphasis on RED activities within these organizations is indicated.

Question 17: Which activities in reliability engineering do the employees in this area mainly perform?

The answers shown in Figure 29 indicate that the collection of machine data, the evaluation of this data, and the compilation of statistics, as well as the creation of FMEAs, RCAs, etc., are among the main tasks of most REDs. Likewise, providing guidance to maintenance management and personnel is a key responsibility in most businesses. Under "others," the following information was provided: maintenance strategy, maintenance audits, and consulting with the site manager.

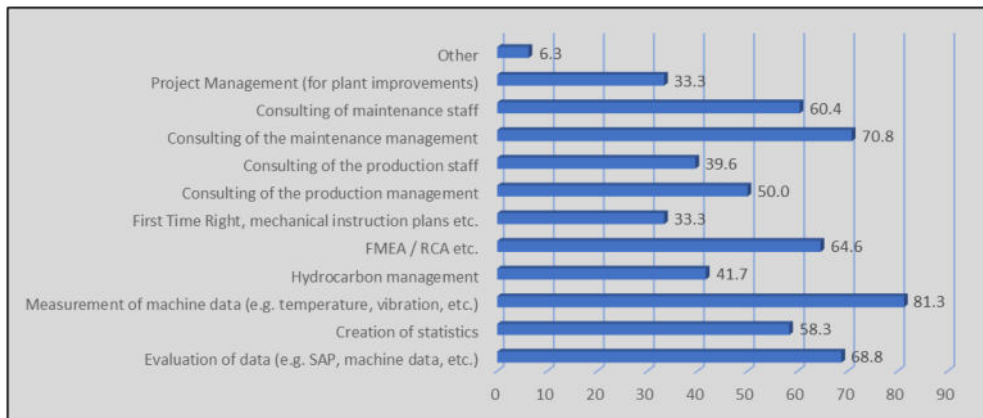


Figure 29: Primary activities of the RED (multiple answers possible) [%]

Here, the focus of most of the REDs is quite clear. On the one hand, the field of work includes apparent plant reference by monitoring the plants and interpreting and presenting the results. Another aspect of the job is technical consulting with specialists and managers.

3.4.3 Section 3 – Budget of Reliability Engineering Departments

This part of the survey explores whether the RED has a dedicated budget, how much of the maintenance budget is used for reliability measures, and whether the RED has already contributed to cost reductions.

Question 18: Does reliability engineering have its own budget for implementing improvement measures?

The research found that 60.4% of REDs have their own dedicated budget for delivering improvements (Fig. 30).

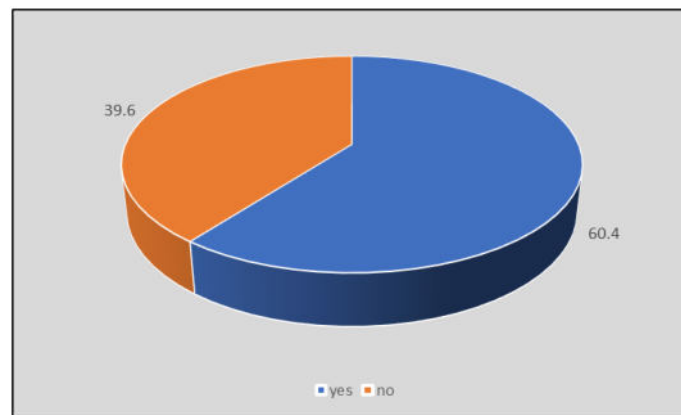


Figure 30: Own budget for improvement measures? [%]

As most REDs have an available budget, it can be presumed that the REDs concerned will assess, design, and realize the necessary measures themselves. These have the trust of the superordinate departments.

Question 19: What percentage of the maintenance budget is spent on reliability measures?

Table 2 shows that only three companies do not spend any money on reliability measures concerning the maintenance budget (MTCE). The spending range is between 0% and 35.0%, which varies according to the company. The mean value is 15% of the maintenance budget. It can be seen that almost all plants spend a part of their maintenance budget on reliability measures (93.7%). One company spends as much as 35% of its maintenance budget on such measures.

Table 2: Maintenance budget spent on reliability measures

Percentage of MTCE budgeted	Quantity	Percentage of participants
0	3	6.3
1	5	10.4
2	1	2.1
4	1	2.1
5	9	18.8
10	8	16.7
15	9	18.8
20	7	14.6
25	1	2.1
30	2	4.2
33	1	2.1
35	1	2.1

This spending illustrates the importance of such measures for the respective companies.

Question 20: Has reliability engineering already contributed to a cost reduction at your site?

In response to this question, six respondents (12.5%) indicated that the RED has not yet contributed to a reduction in costs at the site. If only those participants who already operate a RED are considered here, the picture is that 100% of participants indicate that the RED has already realized cost savings.

This result allows us to draw the conclusion that REDs will fundamentally help reduce costs.

3.4.4 Section 4 – Expected Savings and Goals of Reliability Engineering Departments

In this section, participants are asked about specific savings in various areas for 2019 and 2020. Here, the expectations and the actual savings generated are of interest. Likewise, the key performance indicators and whether REDs have achieved the expected targets are questioned.

Question 21: Reduction in production losses (in percent)?

Figure 31 shows the expected savings compared to the actual savings through the reduction of production losses achieved due to the REDs. The years 2019 and 2020 were analyzed, revealing that the contributing companies exceeded their targets during this period. Even though the average expected savings were 6.6% (2019) and 7.2% (2020), the expectations of the individual companies were quite different. They ranged from 0% to 30.0% for 2019 and likewise from 0% to 30.0% for 2020. Only responses from participants who had already implemented a RED during the survey were considered. It is clearly evident that average expectations were exceeded in both years.

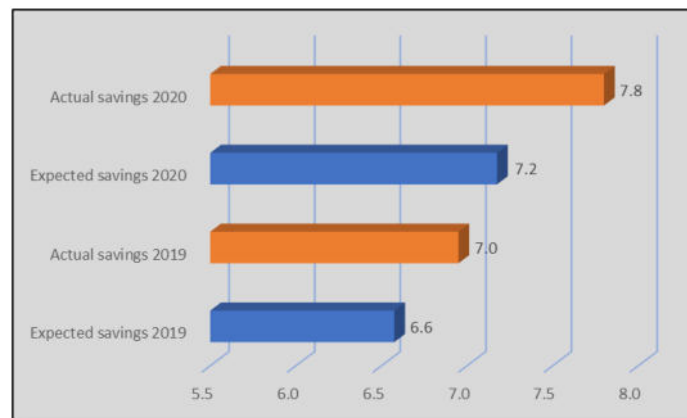


Figure 31: Expected and achieved reduction in production losses [%]

This suggests that the anticipated savings were realistically estimated, and the efforts of the respective REDs even surpassed expectations.

Question 22: Reduction in maintenance costs (in percent)?

Figure 32 shows the expected savings compared to the actual savings realized through reductions in the maintenance budget due to the REDs' actions. It shows that the average expected savings were achieved in 2019. In the following year of the period under consideration (2020), there is a substantial excess of the expected savings. The savings expected by the respective companies varied here for both years under consideration between 0% and 30.0%. Only responses from participants who had already employed a RED during the survey were considered.

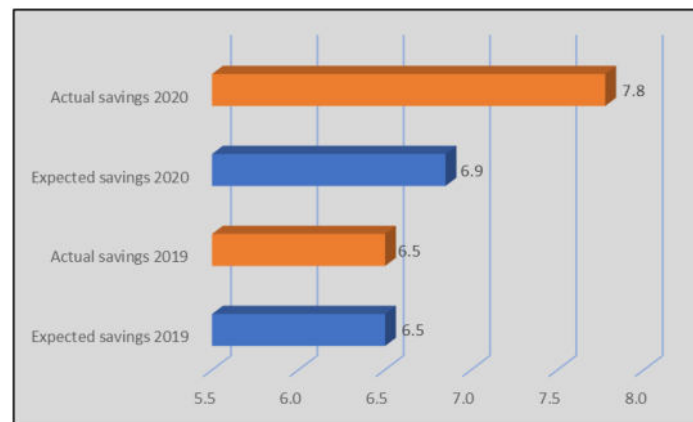


Figure 32: Expected and achieved reduction in maintenance budget [%]

On the one hand, the expectations were fulfilled in 2019; on the other hand, they were clearly exceeded in 2020. Thus, it can also be deduced here that the expectations of the savings potential to be realized by the management were realistic and that the work of the respective REDs was able to meet and even exceed the expectations.

Question 23: Extension of plant operating time (in percent)?

The anticipated increases in production time versus the effective increases in production time resulting from the REDs' activities are illustrated in Figure 33. Similarly, the years under review were 2019 and 2020. It is shown that the expectations of the participating companies were considerably exceeded in the two years considered. The average expectations of the individual companies also differed considerably here. These started at 0% and ranged up to 99.0% expected improvement in production time in both years. Only responses from participants who had already implemented a RED at the time of the survey were considered.

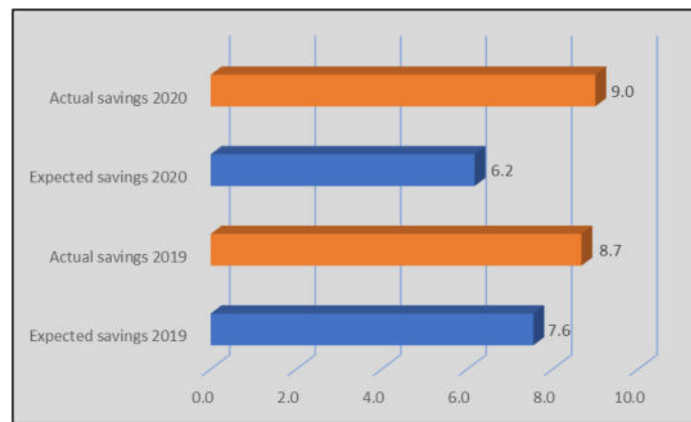


Figure 33: Expected and achieved extension of plant operating time [%]

The graph illustrates the expected average improvements realized in both years under consideration. Here, too, it can be deduced that the expectations regarding the savings potential to be realized were realistic, and the work of the respective REDs even exceeded the expectations placed on them.

Question 24: What potential savings do you or your organization expect in the future?

Figure 34 shows the average savings expected by participants in the future. Across all participants, these are higher than the expected savings for 2019 and 2020. On average, respondents who have launched a RED expect a 12.8% reduction in production losses, a 10.1% decrease in maintenance costs, and a 12.2% extension in production time. Nevertheless, these figures are not essentially different from those of the entire group of respondents.

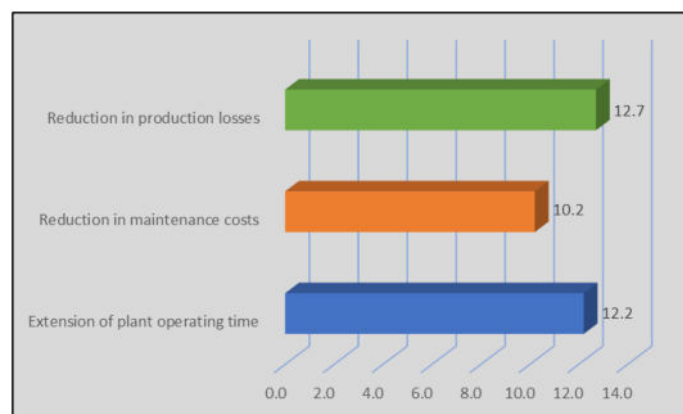


Figure 34: Expected savings in the future [%]

The evaluation of the questions shows that the respective companies' average expectations are definitely higher than those in 2019 and 2020. It can be deduced that the participants see a real opportunity for an increase in cost reduction in the future.

Question 25: Which key performance indicators (KPIs) are used to assess the efficiency of reliability engineering in your company?

The KPIs presented in Figure 35 show a clear picture. The key performance indicators that are used most frequently include production losses, maintenance costs, as well as plant uptime, with just a limited number of exceptions. However, one participant stated that he was not aware of any KPIs. Another wrote that the planned rate compared to the curative is used as a KPI. The most common KPI used for the RED is the reduction of production losses. The chart shows that most businesses use a combination of different KPIs.

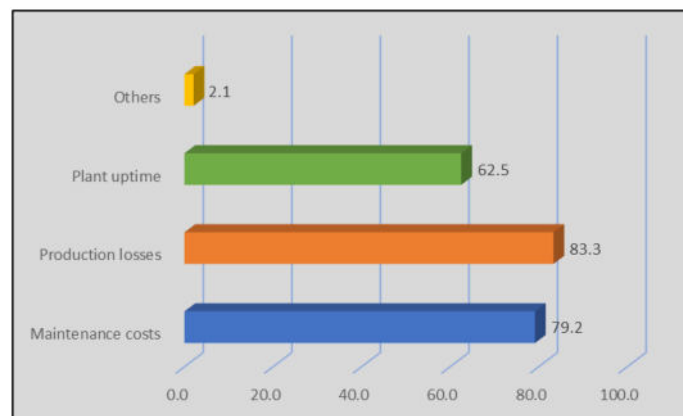


Figure 35: Used KPIs (multiple answers possible) [%]

The participants' answers show that KPIs are widely used, even if sometimes only one of the indicated KPIs is used. Companies feel the need to monitor whether or not the expected successes have been achieved through the RED.

Question 26: Does reliability engineering actually reach the given targets?

The average values across all participants are shown here, related to compliance with the KPIs specified in the previous question (Fig. 36). Only data on KPIs that the participants actually used was considered in the illustration. The data shows that, on average, targets were met mainly at a high percentage. Notably, the

KPI for "reduction of production losses" was successfully achieved by 82.1% of participants.

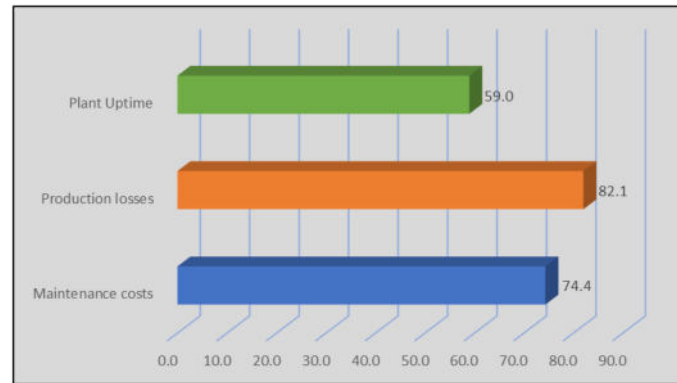


Figure 36: Achievement of the RED targets [%]

This outcome shows that the respective REDs have fulfilled their expectations to a high degree. Nevertheless, management has set achievable targets.

3.5 FURTHER ANALYSIS OF THE FINDINGS

In addition to the direct responses to the questions asked in the online survey, a deeper level of analysis can provide valuable insights. This deeper analysis examines and presents the relationships between selected questions. These relationships and correlations enable a deeper understanding of the survey data and reveal patterns, tendencies, and dependencies that are not immediately apparent when analyzing individual questions separately.

In order to improve the presentation and clarity of the available data, the firms involved in the study were divided into different groups according to the number of staff employed at each site. Instead of adopting a simple classification scheme of small, medium, and large, a more nuanced approach was chosen to account for the diversity in company sizes. This approach involved breaking down the companies into the following categories: those with fewer than or equal to 100 employees at the site, those with 101 to 500 employees, those with 501 to 1,000 employees, those with 1,001 to 2,000 employees, and those with more than 2,001 employees at the site.

a) Relationship between the number of employees at a site, in maintenance, and in a RED

This analysis is intended to establish a link between the overall figure of employees at a site, the number of maintenance staff, and the number of employees in the RED. The evaluation results provided a multifaceted picture of the distribution of employees in maintenance and RED across these different company-size categories. In businesses with fewer than 100 employees at their site, it was found that 11.9% of the employees were engaged in maintenance roles, while 1.0% were in the RED. When considering the proportion of RED employees relative to the entire workforce in maintenance, this ratio amounted to 10.8%. For somewhat larger companies with 101 to 500 employees, a higher percentage of employees, nearly 17.4%, worked in maintenance, and the proportion of RED employees concerning all employees increased to 2.3%. Notably, the percentage of RED employees in the maintenance department rises to 13.0%. In the next group of companies with 501 to 1,000 employees at their site, the percentage of maintenance staff increased further, exceeding 19.3% of the total workforce, making it the highest percentage in the evaluation. However, the percentage of RED employees in this category dropped sharply to only 0.6% of the total workforce, representing a mere 2.9% of all maintenance employees. This was the lowest proportion observed in the evaluation. Moving on to companies with 1,001 to 2,000 employees at the site, there was no increase in the percentage of RED employees compared to all employees, but the total number of maintenance employees decreased.

One surprising finding emerged in the case of companies with more than 2,001 employees at their sites. Despite their large size, the proportion of maintenance employees in these companies was notably low at 12.2% of all employees. However, the percentage of RED employees stood out, dropping to only 0.5% of the total workforce and 4.2% in relation to the share of maintenance employees.

Table 3: Relation number of employees (all, maintenance, RED)

Employees at site	Average number of all employees	Average number of maintenance employees	Average of maintenance employees related to all employees [%]	Average number of RED employees	Average of RED employees related to all employees [%]	Average of RED employees related to maintenance employees [%]
<=100	77.9	9.3	11.9	1.0	1.3	10.8
101-500	321.4	56.0	17.4	7.3	2.3	13.0
501-1,000	828.6	159.6	19.3	4.6	0.6	2.9
1,001-2,000	1566.7	251.7	16.1	10.2	0.6	4.0
>2,001	2733.3	334.2	12.2	14.0	0.5	4.2

These results underscore the varied distribution of employees in maintenance and the RED department across companies of different sizes. The data suggests that a company's size may profoundly impact its workforce composition in these roles, with smaller companies having a different profile than larger ones. The data has been summarized in Tab. 3.

b) Relationship between reporting line and number of employees

This analysis aims to investigate and demonstrate the correlation between the number of employees at a specific site and the reporting line within an organization. Understanding this relationship can offer meaningful views of the organizational structure and dynamics of the workplace. However, the results do not reveal a uniform trend across all these groups. The organizational reporting lines for a RED within these companies appear to be quite diverse.

A varied landscape is observed with companies with fewer than or equal to 100 employees at a given site. In this category, half of the heads of a RED (50.0%) report to the site manager, showing a relatively centralized reporting structure. However, a portion also reports to the head of engineering (16.7%), while others report directly to the maintenance manager or the general manager. This indicates a multi-faceted approach to reporting lines in smaller organizations. A notable shift occurs in the group of companies with 101 to 500 employees at the site. In this category, the majority (70.8%) of RED managers report to the maintenance manager, indicating a more specialized and function-oriented reporting structure. The direct reporting line to the site manager diminishes to 16.7%, and reporting to the engineering manager or general manager becomes even less common. The pattern

continues in the 501 to 1,000 employee group, where the RED predominantly reports to a maintenance manager (88.9%). Reporting lines to the maintenance and engineering manager become less prevalent. However, the picture changes again when analyzing the following group (1,001 - 2,000 site employees). In this category, the reporting structure shifts again, with a substantial proportion (40.0%) of RED managers reporting directly to the site manager. Nevertheless, a comparable proportion still reports to the maintenance manager, general manager, and, for the first time, to global engineering. For companies with over 2,001 employees at a site, the reporting structure remains constant, with a primary focus on reporting to the site manager (50.0%). However, in these larger organizations, the head of RED may also report to the maintenance manager or engineering manager, depending on the specific company's structure. An excerpt of the data is shown in Table 4.

Table 4: Reporting line

Employees at site	RED Manager mainly reports to	Percentage
<=100	Site Manager	50.0
101-500	Maintenance Manager	70.8
501-1,000	Maintenance Manager	88.9
1,001-2,000	Site Manager	40.0
>2,001	Site Manager	50.0

In summary, the analysis reveals that the reporting line to the maintenance manager becomes more relevant for companies with more than 100 employees at the site. Conversely, larger companies with more than 1,000 employees at the site tend to favor direct reporting to the site manager. Additionally, global engineering appears to be involved primarily in larger sites, suggesting a dynamic and evolving organizational structure across various sizes of companies.

c) Relationship between organizational affiliation to a department and the reporting line

This evaluation aims to examine the different reporting structures within different departmental affiliations. It provides insight into who the department heads of a RED within an organization report to their respective supervisors based on their departmental roles.

For those REDs that are organizationally part of engineering, there is a clear and direct reporting relationship with the engineering manager. The department reports directly to the site manager if it is organizationally under the site manager. The same applies to members of an independent central team, where the reporting line also leads straight to the site manager. If the RED is part of the global engineering team, their reporting line also goes to the global engineering. The reporting structure shows two possible paths if the RED is part of the production department. Participants indicated that the REDs report to either the site manager or the maintenance manager.

Several options emerged from the survey regarding the affiliation of the RED to the maintenance department. A predominant pattern shows that in three-quarters of the cases (75.0%), there is a direct reporting line to the maintenance manager. However, the survey also shows that in some companies, the manager of the RED reports directly to the site manager (13.9%), the general manager, the engineering manager, or the maintenance and engineering manager, which is less common.

This evaluation represents different reporting lines within the respective organizational structures. There is no standardized reporting line.

d) Relationship between maintenance strategy and number of employees

The main goal of this analysis is to examine the extent to which a straight link exists between the workforce size at a given site and the maintenance strategy implemented by companies. However, the results present a somewhat mixed picture, suggesting that no one-size-fits-all approach exists in this context. Most companies have opted for a blended maintenance strategy, combining preventive and predictive approaches. It is worth highlighting that only one participating company solely relies on a reactive maintenance strategy. Instead, all other strategies incorporate preventive and predictive maintenance elements or, in some cases, integrate all three approaches. A closer analysis of the data shows that categorizing companies based on the number of employees at their respective sites reveals noteworthy patterns. In the case of smaller businesses with 100 employees or less at their sites and the largest participating companies with over 2,001 employees at their sites, reactive maintenance practices are absent. This suggests that both ends of the size spectrum prioritize proactive maintenance strategies.

However, within the group of companies employing between 101 and 500 individuals at their sites, 20.8% still engage in reactive maintenance, albeit to a limited extent. Among the categories of companies with 501 to 1,000 employees and 1,001 to 2,001 employees at their sites, a larger portion, up to 40.0%, are involved in reactive maintenance activities. This implies that mid-sized companies are more inclined to incorporate reactive maintenance into their overall maintenance strategies. The data is shown in Table 5.

Table 5: Maintenance strategy

Employees at site	Strategy with reactive component [%]	Strategy without reactive component t [%]
<=100	0.0	100.0
101-500	20.8	79.2
501-1,000	33.3	66.7
1,001-2,000	40.0	60.0
>2,001	0.0	100.0

In summary, the data from the surveyed companies highlights an exciting trend. Very small and very large companies tend to move away from reactive maintenance, focusing more on preventive and predictive strategies. In contrast, although these also work primarily preventively or predictively, mid-sized companies are more likely to combine two or all three approaches. This variation in maintenance strategies reflects companies' unique needs, resources, and priorities across different size categories, illustrating that one approach does not fit all in maintenance strategy.

e) Relationship between maintenance strategy and expected and achieved savings

This analysis explores the relationship between the maintenance strategies employed by different companies and the expected versus actual savings achieved. The focus is on two key categories: Companies that use at least some reactive maintenance practices and companies that have opted for preventive, predictive, or a combination of both strategies. When looking at production loss reduction, it

is clear that the expected and realized savings for 2019 and 2020 for companies with a reactive element in their strategy lag behind those companies that rely solely on preventive, predictive, or mixed approaches. Interestingly, in terms of future expectations, the proportion of expected savings is much higher in the reactive group.

A similar scenario emerges when looking at the reduction in maintenance costs. Companies with a partially reactive strategy have lower expectations than those with preventive or predictive strategies. However, when evaluating the actual savings achieved, the companies with a reactive component have less savings archived. Future expectations paint the same picture, with higher expected savings for companies with non-reactive strategies. In terms of extending plant uptime, the difference is even bigger. Companies without a reactive strategy are ahead in terms of both expectations and actual implementation. Only in terms of future expectations do companies with a reactive component outperform their non-reactive competitors. The numerical values are shown in Table 6.

Table 6: Maintenance strategy and savings

	Reduction in production losses [%]					Reduction in maintenance costs [%]					Extension of plant uptime [%]				
	Expectation		Actual savings		Expected future savings	Expectation		Actual savings		Expected future savings	Expectation		Actual savings		Expected future savings
	2019	2020	2019	2020		2019	2020	2019	2020		2019	2020	2019	2020	
No reactive strategy	6.3	6.8	6.3	7.6	11.8	5.6	6.5	6.2	7.1	10.3	7.1	8.1	5.9	8.7	11.3
Partly reactive strategy	3.6	3.8	4.9	3.4	13.9	5.4	5.8	4.5	5.2	7.6	3.6	4.5	3.2	3.8	13.5

A clear pattern can be derived from this analysis. It shows that in all cases, the expectations for savings in the years examined (2019 and 2020) and the savings achieved were higher for companies without a reactive component in their strategy. Nevertheless, companies with a reactive component tend to have higher expectations for future savings, so their future prospects are mostly bigger than those of companies without a reactive component.

This analysis reveals a complex interplay between maintenance strategies and companies' financial performance. While non-reactive strategies generally deliver better results in terms of realized savings, companies that incorporate a

reactive element tend to set themselves more challenging goals for future savings potential. The choice of maintenance strategy appears to be a nuanced decision that involves balancing immediate savings with long-term prospects for cost reductions and efficiency gains.

f) Relationship between the number of employees at a site and the savings expected to be achieved through a RED

This analysis aims to demonstrate the relationship between the size of a site and the anticipated and realized cost savings through a RED. When probing the available data, it turns out that there is no uniform trend discernible in the findings. Nevertheless, a clear pattern emerges showing that substantial savings have been attained across various areas. Nevertheless, it is worth remarking that none of the participant groups completely fulfilled their expectations. What is particularly intriguing is that in most cases, the expectations for future savings appear to be distinctively higher than what was achieved in the years 2019 and 2020, which are examined in the study. These expectations are far higher in certain instances than the savings already realized during these two years. The statistics are shown in Table 7.

Table 7: Site size and savings

Number of employees on site	Reduction in production losses [%]					Reduction in maintenance costs [%]					Extension of plant uptime [%]				
	Expectation		Actual savings		Expected future savings	Expectation		Actual savings		Expected future savings	Expectation		Actual savings		Expected future savings
	2019	2020	2019	2020		2019	2020	2019	2020		2019	2020	2019	2020	
<=100	5.8	5.8	5.2	6.3	13.3	6.7	10.5	8.3	10.3	14.2	2.5	6.7	3.3	6.0	14.2
101-500	6.8	7.8	7.1	8.3	11.6	5.4	6.7	5.3	6.6	9.0	5.8	7.1	4.4	7.9	10.2
501-1,000	4.4	4.7	4.2	5.0	16.8	4.6	4.6	5.2	5.3	9.0	5.6	5.6	3.8	5.4	19.2
1,001-2,000	5.0	5.2	3.6	4.2	14.0	4.8	4.8	4.4	3.4	9.8	20.4	20.4	20.0	19.8	14.6
>2,001	6.3	7.0	9.5	7.5	7.5	12.5	12.5	11.5	12.3	15.0	1.3	1.3	0.8	1.3	2.5
Average	5.7	6.1	5.9	6.3	12.6	6.8	7.8	6.9	7.6	11.4	7.1	8.2	6.4	8.1	12.1

An area that stands out prominently is the extension of plant uptime for the group of companies with 1,001 to 2,000 employees at their site. The expectations and actual savings here are striking when compared to the average expectations across all participant groups. The figures sometimes are more than double or even

triple the average values. This stark contrast can be attributed to one participant who had exceptionally high expectations and successfully realized them. This outlier has a significant effect on the overall statistics.

Conversely, in the same context of extending plant operating time, the group of companies with over 2,001 employees at their site reported relatively low expectations and achieved targets when compared to the average figures. In some instances, these figures are well below the averages of the other groups. The underlying data also reveals that most participants in this category stated that they had no expectations for extending plant operating time, and as a result, they were unable to report any achieved savings.

g) Relationship between the size of the site and the potential to implement savings projects independently

This analysis aims to explore the relationship between a RED's autonomy in executing cost-saving projects and the size of the site in question. In this context, autonomy refers to the ability to implement savings initiatives without requiring prior managerial approval. The goal is to identify any discernible patterns or trends in this relationship. However, surprisingly, this analysis does not reveal a clear and constant trend. Nevertheless, it shows some interesting results, some of which depend on the company's size. In each size group, there are firms where the RED can independently carry out such projects. In particular, companies with 501 to 1,000 employees and those with more than 2,001 employees always have at least some potential for implementing cost-saving projects on their own. In contrast, the group with 1,001 to 2,000 employees at one location is striking. In this category, 60.0% of participants stated that they cannot carry out cost-saving projects independently. This result contrasts the other groups, where the percentage of organizations that can carry out projects partially independently is markedly higher. These details and percentages are further explained in Figure 37 for a visual representation of the data.

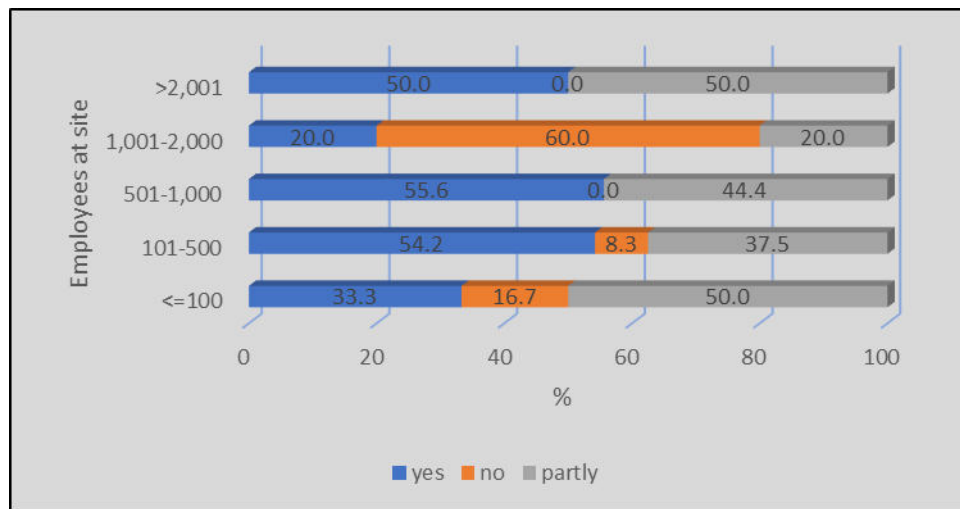


Figure 37: Size of site and own saving projects

In conclusion, the relationship between site size and the ability to run cost-saving projects independently shows interesting variations, although a clear trend is not apparent in this analysis.

3.6 SUMMARY OF THE FINDINGS

The data obtained in the preliminary study is very valuable, as it has never been collected in this comprehension and complexity. Beyond the literature review, a vital database has been obtained.

From the beginning, it was evident that the participant group consisted of a diverse mix of maintenance and reliability engineering professionals, varying in both background and geographical location. While most hailed from Europe, individuals from many different countries participated, with a notable concentration in large-scale industrial regions. The study also unveiled a wide range in the number of maintenance employees, spanning from four to as many as 750 in the participating companies. Concerning reliability engineering staff, most companies had fewer than five employees in this role, with 18% having only one RED employee. Furthermore, the study highlighted that many RED employees held university degrees. Nearly two-thirds (65.6%) of the participants currently had their own RED. Among those without one, 61.9% expressed a desire to launch one.

The findings related to organizational structures were insightful. Precisely 75.0% of REDs were integrated into general maintenance, resulting in 58.3% of RED managers reporting to the maintenance manager and 22.9% to the site manager. Predominant maintenance strategies were preventive and predictive, while reactive strategies were less common, though mixed approaches were also employed. The autonomy of REDs was evident, with 87.5% having the capability to independently or partially execute reliability projects. Notably, the majority of participants expressed satisfaction with their current RED structures. The evaluation of responses regarding the organizational placement of the RED yielded mixed results. Four participants expressed satisfaction with reporting to the maintenance manager. Five participants advocated for integrating the RED into maintenance, while others suggested reporting to production management, the site manager, or even being an independent department reporting to the higher management. There was a consent on the requirement for a close collaboration between production, maintenance, and the RED, along with a desire for an independent budget and project implementation authority. Participants also emphasized the importance of further staff, with one suggesting the RED should constitute 10% of the maintenance team. Other recommendations included having a robust database, a core team for method development, and dedicated personnel for condition monitoring. The focus should be on addressing bad actors and low MTBF; an independent status for the RED was seen as essential. Overall, opinions varied, with most leaning towards integrating the RED into maintenance, but a huge need for more resources was apparent.

A huge percentage of 70.8% of the workforce in reliability engineering exclusively focuses on this field. For participants who mentioned that their reliability engineering employees are not exclusively dedicated to this domain, they reported allocating an average of 35.7% of their work time to other tasks. Primary activities within reliability engineering encompass data collection, data analysis, statistical preparation, and the development of FMEAs and RCAs. Collaborating with maintenance management and other staff is also deemed crucial.

The study also yielded valuable insights into cost-related aspects. Notably, 60.4% of reliability engineering departments maintain a dedicated budget for improvement initiatives. On average, 15% of the maintenance budget is allocated to reliability-related activities, with some companies allocating as much as 35%. A

clear majority of respondents indicated that the involvement of reliability engineering has resulted in cost reductions at their facilities.

Likewise, the study shed light on anticipated savings and targets for REDs. Expectations for cost reductions were found to have been exceeded in several areas, including production losses in 2019 and 2020, maintenance costs in 2020, whereby the expected savings in this area were achieved in 2019, and uptime in 2019 and 2020. Participants anticipate even greater savings, with expected reductions in lost production, maintenance costs, and extended production time averaging between 10.2% and 12.7%. The evaluation of reliability engineering efficiency relies on key performance indicators (KPIs), which include maintenance costs, production losses, and equipment uptime, although there is some variation among respondents. The survey findings indicate that, on average, these KPI goals were achieved with a high degree of success, particularly the "reduction in production losses" KPI, which 83.3% of the respondents met.

Further analysis of the findings delves into various aspects of the survey data to uncover valuable insights. It explores the relationships between different variables and comprehensively explains the data. The analysis explores the relationship between the amount of staff at a site, maintenance employees, and employees in the RED department. It shows that bigger companies tend to have a higher percentage of maintenance employees relative to their total workforce, while smaller companies have a larger proportion of employees in the RED department. The data suggests that a company's size impacts its workforce composition in these roles. The investigation of the reporting line and the number of employees at a site reveals a diverse landscape. Smaller companies often have centralized reporting structures, while mid-sized companies tend to have more specialized reporting lines. Larger companies favor direct reporting to the site manager, indicating an evolving organizational structure. Examining the reporting lines within different departmental affiliations shows a lack of a uniform reporting structure. Each department affiliation leads to different reporting paths, reflecting the complexity of organizational structures. The analysis explores the connection between maintenance strategy and the number of staff, highlighting that there is no one-size-fits-all approach. Smaller and larger companies prioritize proactive maintenance strategies, while mid-sized companies tend to incorporate reactive maintenance. This variation

underscores that maintenance strategies depend on a company's unique needs and resources.

The analysis of maintenance strategy and expected/achieved savings demonstrates a complex interplay. Companies with non-reactive strategies tend to perform better regarding realized savings, but those with reactive elements have partly higher expectations for future savings.

Finally, the analysis examines the relationship between the size of a site and its ability to independently implement cost-saving projects. While there is no clear trend, it shows that groups with 501 to 1,000 employees and those with over 2,001 employees typically have the potential, at least partly, for independent projects. However, the 1,001 to 2,000 employee group stands out, as a sizeable percentage cannot carry out cost-saving projects independently.

In summary, the preliminary study results highlight the critical role of reliability engineering in achieving cost reductions and operational efficiencies across all industries. Overall, participants are satisfied with their organizations' approaches and results. The survey data analysis reveals numerous insights and highlights the different relationships and trends influenced by company size, maintenance strategies, reporting structures, and cost-saving opportunities. These findings highlight the need for tailored approaches to different organizational aspects, as a uniform approach is inappropriate.

3.7 REQUIREMENTS FOR THE MAIN STUDY

The results of the extensive quantitative preliminary study have already provided a wealth of insight into the topics under investigation. The data collected for the first time in this form allows the findings of the previous literature review to be considerably broadened. However, it also clearly shows where the research gaps still lie. These are summarized in Chapter 4.3 - Research Gap. In some areas, the preliminary quantitative study has already provided important information that goes into greater detail. A detailed, much more profound examination of the research gap is required in certain areas. The preliminary study that has been carried out now allows specific, in-depth questions to be derived for the main study (see Chapter 5 – Main Study). The detailed research question and the associated sub-questions are presented in Chapter 4.4 - Detailed Research Questions.

4 RESEARCH DESIGN

4.1 POTENTIAL RESEARCH METHODS

The specialized literature has a wide variety of empirical scientific research methods. Selecting an adequate research method is indispensable to obtaining valid and meaningful scientific results. Consequently, the scientific methods commonly used are explained here in summary.

Bortz and Döring explain that empirical research seeks insights through systematically evaluating experiences (Bortz & Döring, 2006), as needed here. Equally, Baur and Blasius describe the economic sciences as "reality sciences." Therefore, theoretical statements and forecasts must be subject to empirical testing (Baur & Blasius, 2019). The appropriate research methods that promise the best results must be selected to carry out an empirical investigation. The methods literature states that the choice of methods should be as appropriate as possible to the research question (Kuckartz, 2014a). Today, the social sciences provide a wide range of methods. These are constantly expanding and improving (Baur & Blasius, 2019).

The main distinction lies in the research methods, with a clear demarcation between quantitative and qualitative approaches. Raithel also emphasizes the existence of two different approaches to knowledge and research in the social sciences, each rooted in its own clearly defined theoretical framework: the qualitative scientific paradigm and the quantitative scientific paradigm (Raithel, 2008).

It is also pointed out that quantitative and qualitative methods do not exclude each other; they are used according to the research question or level of research (Brühl & Buch, 2006).

Both approaches have historically coexisted, with qualitative approaches frequently being overshadowed by quantitative approaches since the Enlightenment at the most. Depending on the respective field of research, this is still the case today. While psychology, for example, often follows quantitative traditions, in sociology, among others, qualitative research established itself much earlier as a similar approach alongside quantitative methods (Zepke, 2016). There are strong supporters of each research method in the scientific world. Wichmann observes that passionate supporters of quantitative or qualitative research who have little or nothing to gain from the other approach still exist on both sides (Wichmann, 2019). She also points

out that quantitative and qualitative methodologies are grounded in distinct modes of reasoning. They tackle dissimilar inquiries and provide distinct methods of resolution.

Consequently, the outcomes derived from each approach also diverge widely in nature and encompass diverse potential applications (*ibid.*). If both methods are compared, they all have their strengths and weaknesses. Nevertheless, Bauer and Blasius state that the main objective of the social sciences is to answer questions. This approach can be either qualitative or quantitative or a combination of both methods, depending on the context. Therefore, quantitative and qualitative research are not opposites. Instead, they should complement each other (Baur & Blasius, 2019). Kuckartz states that pragmatic positions in the practice of empirical social research have increasingly prevailed in the choice of methods over the past decades (Kuckartz, 2014a).

Quantitative Method

Quantitative research primarily determines numerical values. The name of the research method indicates that quantitative research intends to count and statistically process relevant quantities and their relationship (Reinhardt, 2012). This research method is commonly used in economic and social science studies. Best and Wolf state that quantitative-empirical research is the standard approach in social sciences today (Best & Wolf, 2010). This choice of method allows a comprehensive statistical visualization and analysis of the findings. Raithel acknowledges that quantitative approaches and methods enable an intersubjectively plausible representation of sophisticated patterns by making social circumstances quantifiable and enabling statistical evaluation (Raithel, 2008). In this research method, using a representative sample allows an inference to be made about that of the population (Creswell, 2003). This fact is also underlined by Patton, who states that quantitative methods usually aim at larger samples randomly selected to conclude with certainty from the sample to the population (Patton, 2015). Baur and Blasius state that quantitative research tries to eliminate the researcher's subjectivity as much as possible. For this purpose, the entire research process is organized linearly and divided into individual work steps (Baur & Blasius, 2019).

The quantitative research method has different variants. Surveys can be conducted orally, as an interview with two or more people, or in writing, using a questionnaire. Other differentiating characteristics are shown in Table 8.

Table 8: Differentiating characteristics of surveys (Raithel, 2008, p. 66)

Form of communication	little structured - not standardized
	partially structured - partially standardized
	highly structured - standardized
Type of communication	written
	verbal
Survey setting	single interview
	group survey
Form of implementation	written
	Internet-based
	oral, personal
	telephone-based

The respective characteristics are specified by the type of examination to be carried out.

Online surveys offer a considerable cost advantage (Wagner-Schelewsky & Hering, 2019). According to the ADM (Arbeitskreis Deutscher Markt- und Sozialforschungsinstitute e.V., (i.e., Working Group German Market and Social Research Institutes e.V.) member institutes, in 2016, most surveys were conducted online or via mobile app at 37% (36% by phone, 20% in person, and 7% in writing (ibid.)). There are numerous advantages. In contrast to postal and other non-computerized survey methods, there is no risk of errors due to manual data entry. The data entered is collected directly on a server. The data is immediately available for data cleansing or interim reports (Wagner-Schelewsky & Hering, 2019). Furthermore, because the participants filled out the questions on their computers, the interviewer had no influence over their responses.

Researchers must understand that when numerical values are recorded, a reduction of complexity is deliberately accepted (König, 2016). Beyond that, no natural everyday conversation develops in this type of data collection since the questions are predetermined depending on the method used (Misoch, 2019). In quantitative surveys, the interviewee often has limited room to ask questions or engage in a communicative dialogue to clarify content. The principle of a two-way conversation is not typically put into practice (ibid.). Maintaining consistency by asking

the same questions in a fixed sequence to avoid potential survey errors is essential. Additionally, there is typically no provision for exploring more detailed or probing questions (Bell et al., 2019). Supplementary information that goes beyond the actual question flow is therefore omitted. It is also challenging to go into depth with this type of questioning, especially with closed questions.

Qualitative Method

Qualitative research examines individual cases in detail and evaluates them interpretatively. Gläser-Zikuda specifies that qualitative research in the social sciences attempts to discover how people see an aspect, what personal meaning it has for them, and what motives for action occur in this context. This allows theories to be constructed and conclusions to be drawn for practice (Gläser-Zikuda, 2011). Mayring highlights that the starting point of qualitative content analysis can be any communication, e.g., interview transcripts, documents, etc. However, it does not only analyze the revealed content of the material. (Mayring, 2000). Quantitative and scientific methods have long dominated research and policymaking. Currently, the importance and reputation of alternative qualitative methods are increasing (Walle, 2015). As Walle already pointed out in the previous statement, qualitative research is nowadays entirely accepted in the scientific world.

Qualitative content analysis methods have been met with steadily growing interest in recent years. Many qualitative researchers use them in a wide range of practice areas and numerous disciplines, including education, sociology, political science, psychology, ethnology, social work/social pedagogy, and health research (Kuckartz, 2018). So far, there is no universal procedure for qualitative data analysis. Schreier also points toward different explanations in the literature as to what characterizes the procedure of qualitative content analysis (Schreier, 2014). Mayring, as one of the drivers and founders of the often-used qualitative data analysis methodology, states that qualitative content analysis represents an approach to the empirical, methodically controlled evaluation of even larger text volumes. The material embedded in its communication context is evaluated according to content-analytical rules in the application. There is no attempt to quantify prematurely (Mayring, 2000).

It appears helpful to choose a more open approach, especially when complex questions or issues are to be answered. Reinhardt states that quantitative research

isolates individual factors and uses statistical-comparative analysis to standardize data collection. In contrast, qualitative research is more open and committed to holistic contexts. (Reinhardt, 2012). Baur and Blasius point out that in qualitative research, it is impossible to completely eliminate the researchers' subjectivity and that objects are constantly changing (Baur & Blasius, 2019).

Several variations of interview methods are possible. One source of data input for qualitative research is interviews. Standardized interviews are primarily used in quantitative social research (Misoch, 2019). Semi-open and open interviews are used for qualitative social research. These are not always clearly distinguishable from each other (ibid.). A classification of the interviews sorted by their standardization is presented in Table 9.

Table 9: Classification of interviews according to their standardization, slightly modified (J. Gläser & Laudel, 2009)

Interview	Question wording and sequence	Answer options
standardized	given	given
semi-standardized	given	not given
non-standardized	not given (only topics/topics given)	

Non-standardized interviews are divided into:

- **Guideline interviews** work with predefined topics and a list of questions. The interview guide contains the questions that must be answered. However, neither the question formulations nor the order of the questions are binding. In order to maintain a natural course of the interview, questions from the guide can also be asked out of turn.
- **Open interviews** work with predefined topics but are not supported by an interview guide. These interviews resemble a natural conversation situation. The interviewer works on the topics that interest him or her with freely formulated questions.
- **Narrative interviews** are introduced by a question to which the interviewee is expected to respond with a more extended narrative. For example, the request that the interviewee tell his or her life story. After the narrative is finished, the interviewer has the opportunity to ask follow-up questions. These follow-up questions intend to stimulate narratives again (J. Gläser & Laudel, 2009).

A frequently used variant is the expert interview. The exact definition of expert interviews is vague despite the frequent use of the method in practical research. The method describes, somewhat imprecisely, a specific interview form. In research practice, this method refers to various types of semi-structured guided interviews. Expert interviews are not determined by content or method but only by the group of people to be interviewed (Misoch, 2019).

In qualitative expert interviews, three variants have emerged:

- **Explorative expert interviews** are used in a subject area that has been little researched to prepare for general information gathering, preparation for a primary systematic investigation, or a basic discussion to identify relevant experts.
- **Guideline-based expert interviews** are more structured forms of questioning to obtain hard facts. These facts cannot be gathered from other sources or can only be obtained to a limited degree. The interview guide gathers specific information required to answer an already precise research question.
- **Plausibility interviews** may be helpful after the empirical research program has completed its results. The goal is to either come up with practical recommendations for action or get hints for presenting the research results (Kaiser, 2014).

By passing on their knowledge of facts and experience, the experts interviewed can act as advisors and knowledge providers. With this, good access to fields of knowledge is opened with little effort (Helfferich, 2019).

Furthermore, qualitative research starts from the premise that a direct one-to-one representation of reality is fundamentally unattainable. It meets this challenge by explicitly orienting the research process towards it and emphasizing the subjective perspectives of the researcher and the persons studied and their interactions. (Schumann, 2018). Additionally, it is essential to consider that qualitative research follows a cyclical research approach, where the processes of data collection, data analysis, and data interpretation continually interact and inform each other (Heiser, 2018). It must be considered that qualitative investigations are always more time-consuming (König, 2016). Moreover, the ability to generalize findings is typically limited because the focus is on in-depth analysis of a small number of cases (Heiser, 2018). In qualitative interviewing, interviewers often have the

flexibility to diverge widely from the predefined schedule or guide. They may introduce new questions that align with the interviewee's responses and may even modify the phrasing of questions. Furthermore, it is common for the interviewee to be interviewed repeatedly, sometimes on multiple occasions, to gather a more comprehensive understanding of their perspectives and experiences (Bell et al., 2019). Overall, the researcher has a considerable influence on the interview outcome. For example, the chances of success of an expert interview depend on how the interview is conducted, the flexibility of the researcher, and the balancing of confidentiality and traceability. Decisions must be made following the research objectives and the needs of the analysis (Kaiser, 2014).

Triangulation

A specific research methodology is the so-called "triangulation," which has been established for quite some time and tries to eliminate the strict separation between quantitative and qualitative research approaches. This method can be categorized into four fundamental types: (1) Data triangulation, which encompasses variations in data collection related to time, space, and individuals involved. (2) Investigator triangulation, where multiple observers are employed instead of a single one. (3) Theory triangulation involves utilizing more than one theoretical framework to interpret the phenomenon. (4) Methodological triangulation entails using multiple methods, potentially involving both within-method and between-method approaches. Furthermore, multiple triangulation involves combining various elements within a single study, such as multiple observers, theoretical perspectives, data sources, and methodologies. Additional types of triangulation, including reflexive, structural, and multipurpose, have also been recognized (Denzin, 2007). Bell, Bryman, and Harley state that in applying triangulation to study social phenomena, more than one method or data source is used (Bell et al., 2019). Flick notes that triangulation is a term often used in qualitative research. This use is done with different objectives, sometimes linked with various myths and reservations. A discussion occurs within the framework of the quality of qualitative research and in the context of linking qualitative and quantitative research (Flick, 2011). Reinhardt further describes that triangulation can be used to combine quantitative and qualitative methods. A connection between different qualitative methods is also possible (Reinhardt, 2012). Mackey and Gass likewise specify that the researcher

alleviates concerns associated with diverse qualitative data collection methods by utilizing multiple means of data collection, recognizing that a single method alone is insufficient to provide adequate support and that the study and its conclusions may require validation from two or more independent sources (Mackey & Gass, 2005).

Triangulation involves taking different perspectives on an object under study to answer research questions. A concretization of these perspectives takes place in the different applied methods and the different chosen theoretical approaches. Both should be related to or linked to each other. Reference is made to the different types of data being combined, taking into account the theoretical perspectives applied to the data in each specific context. These perspectives should be treated and implemented equally and with equal consistency. Triangulation can generally increase knowledge and insights at multiple levels and over a greater distance than a single methodical approach. Different methods or different types of data are conceivable (Flick, 2011).

According to Mayring, the triangulation model represents the connection between qualitative and quantitative analysis steps and is the most complex interweaving of qualitative and quantitative analysis steps that occurs in one analysis process. Questions are approached from several angles and with different methods. The goal is not to determine which analysis approach produces the most accurate results. Instead, the results should support each other. The final results are represented by the intersection of the individual results (Mayring, 2001).

Triangulation, however, is not equally popular everywhere. Kuckartz explains that while triangulation has been widely used in Germany for some time, it has not gained the same level of acceptance in the USA (Kuckartz, 2014a). Explained in a simplified way, triangulation describes that a research object is viewed from at least two sides. This view is possible using different methodological approaches (Flick, 2011).

This method is subject to criticism, too, at least in parts. One criticism of the triangulation approach is the assumption that different methods have the same explanatory power for the research question. However, the situation in a group discussion, for example, can produce completely different results than in a face-to-face, in-depth interview (Kuckartz, 2014a). Bell, Bryman, and Harley also point out that in conducting a triangulation study, it is essential to acknowledge the potential

for non-concordant outcomes, which prompts consideration of the appropriate strategy for handling incongruous results. One option is to designate a single dataset as conclusive. Nonetheless, optically and capriciously prioritizing one dataset over another is suboptimal to resolve disparities arising from a triangulation study (Bell et al., 2019). Critics argue that triangulation may not always be appropriate, especially in research informed by poststructuralism and cultural studies. They emphasize the importance of acknowledging diverse and contradictory perspectives. Some criticisms challenge the compatibility of quantitative and qualitative paradigms in triangulation, suggesting that the underlying philosophies may be fundamentally incompatible (Denzin, 2007). Hammersley states that some methodological literature views triangulation as merely a validation technique that reduces the entire research process to a set of technical procedures. This approach, often criticized by qualitative researchers, neglects the crucial interpretive judgment essential to research (Hammersley, 2008). However, Cowman also points out that triangulation can also present challenges. When researchers initially acknowledge the benefits of employing triangulation, they may struggle to differentiate between the selected methods. This could result in a situation where a large amount of data is collected but cannot be thoroughly analyzed or can only be examined at a superficial level. (Cowman, 1993).

Mixed Methods¹

Another combination of methods is the so-called mixed method. Flick states that mixed methodologies primarily aim to enable a pragmatic linkage of qualitative and quantitative research, which should end paradigm wars (Flick, 2011).

Mixed methods research is an investigative approach in which quantitative and qualitative data are collected. This research approach involves integrating the two forms of data and using different designs. These can include philosophical assumptions as well as theoretical frameworks. The core idea of this approach is that combining qualitative and quantitative methods offers a more thorough understanding of a research problem than relying on either method alone (Creswell, 2014). Wichmann observes that, despite methodological differences, the linking of

¹ Some writing also refers to "mixed methodology." This designations can be regarded as equivalent.

quantitative and qualitative approaches in the form of mixed methods approaches is becoming more common. Through an analytically separate consideration of the two approaches, it is still necessary to first develop a fundamental understanding of each approach's differentiation, benefits, and added value (Wichmann, 2019).

This approach to answering research questions is more elaborate than an attempt to answer them through only a quantitative or a qualitative research method. An attempt is made to closely combine two very different research methods, which requires much more methodological knowledge than the one research method-only approach. Thus, more extensive preparatory work is required. Kuckartz indicates that more knowledge and skills are required to execute a mixed-methods project competently. This effort is not the same as working within a method range (Kuckartz, 2014a). When conducting mixed methods research, knowledge of quantitative and qualitative methodologies is required (McKim, 2017).

The popularity of the mixed methods approach is growing. Kuckartz writes that mixed-methods approaches have tremendous interest, especially in the English-speaking world. Increasingly, researchers in different scientific disciplines are working with designs that use quantitative and qualitative methods (Kuckartz, 2014a).

There is no uniform approach to the use of mixed methods. Instead, there is also a large, sometimes even unmanageable, representation of the methodological possibilities in this field. These vary depending on the author. Only a few primary forms have established themselves in the scientific world. Creswell already identified criteria or dimensions for deciding on a mixed-methods design (Creswell, 2003). This categorization was adopted by almost all design classifications formed by other authors (Kuckartz, 2014a).

The following criteria should be considered in this systematic approach: First, the order in which quantitative and qualitative studies are conducted must be determined. Then, it is vital to prioritize the diverse types of studies within the research and indicate which of them has more weight. In addition, it must be decided when the combination of quantitative and qualitative data or results should occur. Finally, it is vital to assess the role of the theoretical perspective in the research design. It must be determined whether the theoretical framework is implicit or whether it actively shapes the overall design (Kuckartz, 2014a).

Similarly, Creswell provided a system for distinguishing the main dimensions of a mixed-methods study. This system is shown in Figure 38.

Implementation	Priority	Integration	Theoretical perspective
• No sequence - concurrent • Sequential - qualitative first • Sequential - quantitative first	• Equal • Qualitative • Quantitative	• At data collection • At data analysis • At Data interpretation • With some combination	• Explicit • Implicit

Figure 38: Decision choices for determining a mixed methods strategy of inquiry (Creswell, 2003)

Based on the information contained in this matrix, several important questions arise. First and foremost, the order in which the quantitative and qualitative data should be collected in the proposed study must be considered. In addition, it is crucial to determine the relative priority assigned to collecting and analyzing quantitative and qualitative data. Another important aspect is the timing of integrating quantitative and qualitative data and their respective results into the research project. Finally, it must be decided whether an overarching theoretical perspective such as gender, race/ethnicity, lifestyle, and socioeconomic class should be incorporated into the study (Creswell, 2003).

According to Creswell, there are different typologies for classifying and identifying mixed-method strategies (Creswell, 2014). Based on his classification, three basic designs can be found in Figure 39.

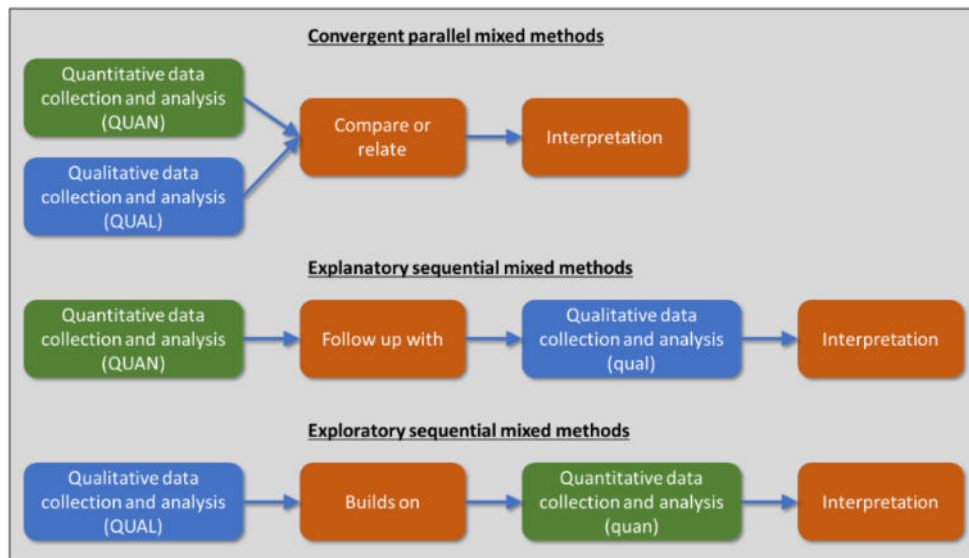


Figure 39: Three basic mixed methods designs (Creswell, 2014, p. 220)

The **convergent parallel design** is the most common research design in mixed methods research. In this approach, quantitative and qualitative data are collected independently, evaluated independently, and compared to determine whether the results complement or contradict each other. The basic assumption here is that qualitative and quantitative data yield different types of information (Creswell, 2014). Likewise, by analyzing the two forms of data in parallel, a more wide-ranging comprehension of the variables and their relationships is achieved (Tashakkori & Teddlie, 1998). Creswell and Plano Clark explain that the fundamental concept involves comparing both data sets' outcomes to comprehend a problem better. This comparison aims to confirm the results achieved through one approach by cross-referencing them with the other. Additionally, it seeks to ascertain whether participants' responses align when assessed through quantitative predefined scales and when presented with open-ended qualitative inquiries. Essentially, the two datasets are integrated to facilitate a more comprehensive analysis (Creswell & Plano Clark, 2018). Bell and Bryman state that this design approach is commonly linked to triangulation efforts, wherein the researcher intends to juxtapose and contrast the outcomes derived from both sets of research methods. Additionally, it is often employed in scenarios where the researcher seeks to mitigate the limitations inherent in quantitative and qualitative research by leveraging the respective advantages of each approach. (Bell et al., 2019).

The **explanatory sequential design** approach is beneficial for researchers with strong quantitative backgrounds or those who are relatively new to qualitative research. It is trying to build a bridge between the quantitative and qualitative research methods and defines a two-phase project. First, quantitative data are collected and analyzed. The second qualitative phase then builds on the results. The main reason for this research approach is to use the qualitative data to explain in more detail the quantitative data collected first (Creswell, 2014). The aim is not simply to provide supplementary information but to close the explanatory gaps the quantitative study has left behind (Kuckartz, 2014a). This approach becomes necessary when the researcher perceives that the overarching patterns of relationships identified through quantitative research demand an explanation that cannot be adequately provided by quantitative data alone. It is also employed when a more profound understanding or additional insights into the quantitative findings are needed. In essence, it serves to enhance the comprehensiveness and depth of research by integrating both quantitative and qualitative data to offer a more complete picture and richer explanation of the research outcomes (Bell et al., 2019).

The **exploratory sequential design** is a research approach that involves a systematic two-stage process to investigate a particular phenomenon. In the first stage, qualitative data are collected and analyzed to gain an in-depth understanding of the topic under study. This qualitative phase helps researchers develop a solid knowledge base and generate hypotheses. Quantitative data is collected and analyzed in the second phase to gain a broader perspective. This design allows researchers to begin with qualitative exploration and then proceed to quantitative inquiry, providing a comprehensive research approach (Creswell, 2014). This approach is often linked to studies where the researcher intends to formulate hypotheses or initial ideas, which can subsequently be examined using quantitative research methods. It is also commonly employed in research endeavors to craft research tools like questionnaire items, which can later be utilized in quantitative investigations. Another fundamental purpose is to complement qualitative findings with quantitative research, thereby enabling the assessment of the breadth and applicability of the qualitative results (Bell et al., 2019).

Criticism of mixed methods emphasizes that they are not a universal solution for scientific knowledge and that the choice of methods should depend on the research object. Not all methods can be combined equally well, so deciding for or against specific methods requires a high level of methodological knowledge. Researchers should work in teams, including generalist networkers and specialized methodological experts, to realize the full potential of mixed methods research (Cloos et al., 2021). From a critical perspective, mixed methods research requires an additional investment of time by the researcher because both quantitative and qualitative data must be collected and analyzed. Likewise, researchers must have an affinity for quantitative and qualitative research methods and be proficient in both (Creswell & Creswell, 2018). Some researchers have expressed concerns regarding mixed methods research, contending that it places excessive emphasis on gathering and analyzing data, often at the expense of prioritizing the interpretation and synthesis of results (Bazeley, 2018). Likewise, incorporating non-numerical and numerical data in mixed methods research poses a formidable challenge. Qualitative and quantitative approaches employ distinct methods to validate research outcomes. Quantitative research emphasizes validity and reliability, whereas qualitative research relies on quality criteria to uphold rigor (Adu et al., 2022).

Triangulation and Mixed Methods – all the same?

There is an imprecise separation between the two approaches. Several authors explain that, furthermore, regarding the concept of triangulation, other authors have used other terms to describe the combination of different research methods, like multi-method, methodological mix, combined, integrated mixed, and multiple methods. However, the terms are sometimes used inconsistently (Creswell, 2003; Tashakkori & Teddlie, 1998; Teddlie & Tashakkori, 2003). Kuckartz further explains that different terms in scientific literature refer to the combination of qualitative and quantitative methods. Mixed methods, the terms triangulation, method integration, method combination, and others, are used. The impression is that these terms are interchangeable and practically synonyms. However, each of these terms has its own history. Overlapping also occurs. (Kuckartz, 2014a).

It must be clearly stated that triangulation and mixed methods are different methodological approaches. The mixed-methods community does not see mixed methods as a subset of triangulation. Rather, mixed methods represent the broader

concept. Here, the focus is not on measurement and validation. It involves a choice of methods that correspond with the research problem. On the other hand, triangulation is an overall conception of validation. The concept can also be described as an enrichment of perspectives that is quite distant from concrete forms of implementation and design (Kuckartz, 2014a). In mixed methods approaches, numerous aspects of triangulation are addressed, or various forms of triangulation are incorporated into the research designs, primarily focusing on achieving triangulation through both data and methodological means (Grecu & Völcker, 2018).

Triangulation and mixed methods are two sophisticated research approaches that can give a more comprehensive understanding of complex research questions—the main difference between the two lies in their goals and how methods are integrated. Triangulation seeks to enhance the validity and reliability of research findings by utilizing multiple methods or data sources. Researchers conduct separate analyses and compare results to minimize potential bias. Mixed methods, on the other hand, actively integrate qualitative and quantitative research approaches into a single study. Quantitative and qualitative data are collected, analyzed, and linked to provide deeper and broader insights. Triangulation and Mixed Methods provide essential tools for researchers to improve the quality and depth of their studies. The choice between the two depends on the specific research objectives, the nature of the problem being studied, and the resources available. Both approaches help enrich research in various ways and deepen understanding of complex phenomena.

4.2 DETERMINATION OF RESEARCH METHOD FOR THE MAIN STUDY

Selecting a suitable research method is a pivotal decision in any research endeavor. In the context of the current research objective, it is vital to recognize that various methods and approaches could, in principle, be considered. Choosing between a quantitative, qualitative, or mixed methods approach necessitates careful consideration. Furthermore, numerous variations and characteristics of research designs exist within each of these broad categories. In this particular study, the qualitative approach emerges as the most suitable. The reason for this is that, firstly, the qualitative approach seeks to comprehend phenomena from an "inside-out" perspective, delving into the viewpoints of the subjects under investigation. It is

inherently subject-oriented, focusing on the rich and nuanced exploration of content and processes. This approach aims to identify individual perspectives, attitudes, and motives and capture subjective realities and theories of reality, including situational interpretations, motives for action, and everyday theories (Misoch, 2019).

Moreover, qualitative research often involves the exploration of previously uncharted territories or the investigation of hitherto unknown facts, shedding light on new aspects of understanding. It actively acquires self-interpretations from participants and precisely clarifies manifest and potentially latent structures of meaning (*ibid.*). Importantly, in qualitative research, the emphasis lies on not achieving representativeness in the statistical sense but rather in the exemplary sense by forming typologies that provide deeper insights into the research domain. This approach strives to generalize findings by elucidating broader patterns and themes inherent in the data (Misoch, 2019).

Qualitative research approaches research areas with open and flexible methods, eschewing standardized survey instruments. Instead, they employ non-standardized data collection techniques with the overarching objectives of gaining understanding and insight. This method is well-suited for uncovering the subjective constructions of reality, analyzing the production of social reality, and (re)constructing meaning, which is intrinsic to understanding the sense-making processes.

After thoroughly evaluating the research questions and objectives, it is clear that the qualitative approach is the most suitable method for this study. It allows for a thorough and in-depth analysis of the research question, aligning with the need to explore the subject's perspective, examine complex phenomena, and develop a detailed understanding of the research area.

The implementation is to take place as expert interviews. Expert interviews are an essential tool for research for several reasons. First, they provide access to specific expertise and a wealth of experience that may not be available through other sources of information (J. Gläser & Laudel, 2009). Second, expert interviews offer the opportunity to clarify and elaborate on complex topics and issues first-hand, leading to a better understanding. Third, they allow the collection of current information and developments in a particular area. Fourth, expert interviews facilitate face-to-face interaction and allow questions to be asked and uncertainties to be clarified.

4.3 RESEARCH GAP

The research gap can be seen even more clearly, built on the descriptions and considerations in the preceding chapters, particularly the data from the literature analysis and the wealth of specific data from the descriptive preliminary study conducted. The individual research gaps are presented in more detail below:

a) It is only partially known how a RED can be organizationally embedded in an (existing) maintenance department and corporate structure to improve a manufacturing company's performance.

b) The detailed reasons why companies decide to introduce a RED have not been sufficiently researched. It is unclear what motivations and objectives are behind this decision.

c) The management of a manufacturing company has certain expectations of a RED, but these are not well documented.

d) Information on the success of reliability engineering departments and the reasons for this is largely lacking. It is essential to understand what measures and practices contribute to improving reliability.

e) When the objectives of a RED are not met, there is no information on what factors and barriers are causing this. This is important in order to take measures for improvement.

f) The core tasks of a RED and performance metrics are only partially documented.

g) There is limited guidance or proposals on how to enhance the maintenance performance of organizations using separate REDs.

h) Most existing approaches and proposals on the above topics are rarely based on empirical research. There is a lack of scientifically sound findings.

This thesis focuses on these research gaps and addresses the most relevant questions on these topics with the research question and related sub-questions (presented in the following sub-chapter).

4.4 DETAILED RESEARCH QUESTIONS

Through the preceding presentations, it is clear that a specific research question must be formulated with corresponding sub-questions. This step is essential to comprehensively and effectively address the identified research gaps. These sub-questions help answer the main question because the main question is too broad to be answered directly. The main question can be answered comprehensively by combining the answers to the sub-questions (White, 2009). The gaps in the existing literature must be considered when developing these research questions. These questions should encapsulate the core of the research problem and guide the research process, ensuring a comprehensive exploration of the topic. The research question, which serves as the central hub of the study, should be concise and clearly defined. It outlines the study's primary focus and provides the framework for the research. The sub-questions, on the other hand, help to break down the main question into manageable components. They provide a structured approach to the research and allow for a systematic analysis of various aspects related to the main research question. The initial research question and its initial sub-questions presented at the beginning of the thesis in Chapter 1 - Introduction were revisited and elaborated in more detail, predominantly based on the preliminary study results. This process ensures that the study remains focused and can be adapted to new insights. This iterative process contributes to the general quality and deepness of the research results and conclusions.

Research Question

RQ: What are the key operational and organizational components for reliability engineering departments to improve a company's performance in the manufacturing industry?

Sub-questions

SQ1: What are the anticipated outcomes or benefits that companies or certain facilities aim to achieve when establishing a reliability engineering department?

SQ2: What are the expectations and performance indicators that companies associated with the contributions of a reliability engineering department in terms of cost savings, minimized production losses, and increased equipment uptime?

SQ3: What methods and criteria do companies or facilities employ to assess the effectiveness and impact of their reliability engineering department?

SQ4: What organizational strategies and practices are employed to integrate a standalone reliability engineering department into the overall company structure?

SQ5: What factors and considerations, beyond immediate cost analysis, influence the perceived impact of establishing a separate reliability engineering department on a company's profitability?

5 MAIN STUDY

5.1 DATA BASIS

5.1.1 Sampling

In order to select the appropriate participants, it is first essential to visualize who has the needed information. Obtaining all the necessary information means interviewing several experts, each of whom has different information due to their current or past professional activity. It will hardly ever be the case in investigations that one interviewee has all the relevant information. However, even in this case, one will not limit oneself to one interview (J. Gläser & Laudel, 2009). In qualitative interviews, the crucial factor is not the number of individuals being interviewed but rather the composition of the interviewees. It is essential to aim for a substantial gain in insights by selecting interview participants (Dimitrova, 2008). Bortz and Döring note that due to the resource-intensive nature of qualitative methods, the number of people studied is much smaller than in quantitative research (Bortz & Döring, 2006). The three possible strategies of participant selection mentioned in the methodological literature are purposive, random, and convenience. The basic idea of purposive sampling is to select professionals with a substantial amount of information to answer the research question (Schreier, 2018). Since an adequate implementation of a pure random sample is often impossible due to the limited number of participants, researchers do not use such random samples. It should be noted, nevertheless, that qualitative social researchers do not fundamentally reject the importance of random sampling (Lamnek & Krell, 2016).

Only highly specialized professionals with a wealth of maintenance and reliability engineering knowledge are eligible to respond to the survey. A selection by random sampling or convenience sampling cannot be expected to reach such specialists, as this is a very limited group. Kuckartz also argues that random selection in qualitative analysis should be avoided wherever possible (Kuckartz, 2014a). According to Patton, purposive sampling is about selecting information-rich cases whose study will shed light on the questions under study (Patton, 2015). Instead of purposive sampling, the term "purposeful sampling" can also be used. There is generally no difference in meaning (*ibid.*). Purposive sampling is typical for qualitative research (Kuckartz, 2014a). Przyborski and Wohlrab-Sahr point out that the

different sampling methods can be effectively combined with each other, for example, by applying them at different stages of the research process. They can support and complement each other (Przyborski & Wohlrab-Sahr, 2014).

Misoch emphasizes the importance of establishing access to potentially interested individuals when conducting qualitative interviews. This entails that the individuals involved should be willing to dedicate time to the interview and actively participate in this demanding process (Misoch, 2019).

Three critical criteria were established as prerequisites to be eligible for participation in this study: (1) The participant should have a professional background or experience in maintenance, reliability engineering, production management, or maintenance consulting. This criterion ensures that participants possess a relevant professional foundation in the subject matter. (2) The participant should demonstrate a substantial connection to reliability engineering within their professional activities. This criterion underscores the importance of participants having direct involvement or a substantial link to the field of reliability engineering. (3) It was essential for participants to have held or currently hold leadership or technical responsibility positions in the areas mentioned above—this criterion aimed to include individuals with a high level of expertise and authority within their professional roles. The author accurately assessed the professional qualifications of each potential participant individually to ascertain their alignment with these criteria. To achieve this, an initial screening was conducted based on the professional resumes of the potential candidates. These resumes were partially accessible to the public (e.g., on the company website) or were submitted by the participants. Following this, all candidates were reached out to via telephone to discuss and ensure a detailed alignment with the previously specified criteria.

The participants were primarily recruited from professional associations focused on reliability or maintenance, of which they held membership. These associations encompassed the Verein Deutscher Ingenieure (i.e., Association of German Engineers, Germany), the Institution of Mechanical Engineers (UK), and the EFNMS network - European Federation of Maintenance Societies vzw - The European network for maintenance in industry (Belgium). The identification of suitable participants was also influenced by recommendations from members within these networks. It is essential to note that all participants, whether directly from the associations or through their recommendations, underwent the thorough screening

process, as mentioned above, to ensure their suitability founded on the specified criteria. This meticulous selection process guaranteed that participants possessed the requisite qualifications and experience pertinent to the study's focal areas.

5.1.2 Sample Size and Theoretical Sampling

The sample size in qualitative research is discussed controversially (Schreier, 2018). Kaiser explains that as the aim is not to generalize, there is also no claim to interviewing a representative sample or even all relevant experts. Instead, in qualitative interviews, the participants are selected purely based on content (Kaiser, 2014). Kuckartz states, more generally, that the qualitative survey sample is usually smaller than the quantitative survey sample (Kuckartz, 2014a). This is also supported by Patton, who states that qualitative studies typically focus on relatively small samples, even single cases ($n = 1$), to study and understand a phenomenon in a detailed, in-depth manner (Patton, 2015). It would be possible to imagine that this sample could be formed from the sample already realized for the preliminary study that has already been carried out. In practice, however, this is only partially achievable, as the preliminary study was conducted anonymously. At the time, those contacted were actively encouraged to pass on access to the survey to other suitable participants or were informed by the various professional associations contacted. Thus, this approach has limited practicality.

In theoretical sampling, the selection of cases to be investigated is not determined from the outset but instead selected step by step in the interplay between data collection, development of theoretical categories, and further data collection. This takes place in an iterative process in which the theoretical categories obtained are reviewed and refined while, at the same time, the variance in the field of investigation is explored. This process is continued until theoretical saturation is gradually reached (Przyborski & Wohlrab-Sahr, 2014).

Saturation is the prevailing guiding principle in evaluating the sufficiency of purposive samples in qualitative research (Morse, 2015). Saunders, Sim, Kingstone, Baker, Waterfield, Bartlam, Burroughs, and Jinks also clarify that saturation has become a recognized methodological principle in qualitative research (Saunders et al., 2018). Nevertheless, there has been a lack of clear guidance regarding evaluating saturation and the requisite sample sizes to attain it (Hennink & Kaiser, 2022). Also, Guest, Bunce, and Johnson describe that there are practically no existing

guidelines for identifying non-probabilistic sample sizes (Guest et al., 2006). Glaser and Strauss indicate that the initial stage of the research does not permit the determination of the required sample size; only upon concluding the research can the researcher ascertain the appropriate sample size (Glaser & Strauss, 2010).

A study by Hennink and Kaiser examined the number of participants required to reach saturation, i.e., a point at which additional participants no longer provide new information or insights (Hennink & Kaiser, 2022). However, this study primarily investigates research with relatively homogeneous study populations and narrowly defined objectives. This characteristic of the studies they referenced limits the generalizability of their findings to research with diverse populations and broader research objectives. This study can, therefore, only be considered a loose reference point. The limitations of their study mean that the number of participants required for saturation may vary in different research contexts. According to Hennink and Kaiser's findings, the average number of interviews required to reach saturation ranged from nine to 17 interviews (*ibid.*). These figures should be interpreted with caution as they take into account the specific characteristics of the study, such as the variety of the study population and the particular nature of the research goals, which may affect the sample size required to reach saturation. However, the actual sample size for this research was determined through the interviews conducted as part of the theoretical sampling process.

Theoretical sampling has gained considerable prominence as the authentic sampling strategy in qualitative research (Flick, 2022). This strategy basically refers to the process of data collection aimed at generating theory, during which data are collected, coded, and analyzed in parallel. Furthermore, it is decided which data to collect next and where to find it (Glaser & Strauss, 2010). This includes checking for the theoretical saturation of the data. Initially, this concept came from grounded theory (Creswell, 2014). This method is used to prove theoretical saturation in the context of this work. This criterion determines when the questioning can be stopped concerning the respective category (Glaser & Strauss, 2010).

Theoretical saturation describes the point in the analysis at which additional material and further evaluations no longer yield any new properties for the category. Also, no relevant refinement of the knowledge about this category can be expected anymore. The rationale behind this termination criterion is to determine when examples of a concept or category are repeated in the material (Flick, 2022;

Strübing, 2014). Theoretical saturation is achieved with the help of parallel data collection and analysis (Glaser & Strauss, 2010).

Determining the occurrence of theoretical saturation per category is subjective and poses a high risk for the researchers. The criterion that the data no longer yields anything new is subject to interpretation and cannot be derived objectively from the data. However, this does not affect the criterion of theoretical saturation itself. To do so, researchers must demonstrate plausibly why they believe a category is sufficiently empirically saturated based on the data they have (Strübing, 2014). Glaser and Strauss also point out that saturation can never be achieved by studying only one incident within a single group (Glaser & Strauss, 2010).

The eventual sixteen interviewees in the survey provided sufficient responses. These are presented in anonymized form in Table 10.

A systematic and strategic approach was taken to sequencing the participants to gain comprehensive insights into the maintenance and reliability engineering field. The sequence of interviews was carefully planned to ensure a well-rounded perspective and to include different roles within the organizational hierarchy.

The first interview with a director of maintenance and engineering (participant 11) served as a foundational step to obtaining basic information about the subject area. Subsequently, a production manager (participant 10) was interviewed to provide insights from the customer's perspective² and to deepen the understanding of the broader operational context. Subsequent interviews were targeted at experts directly involved in reliability engineering, including both reliability engineers and reliability managers (participants 12, 9, 2, and 1). This approach aimed to delve into specific aspects of the field and gain nuanced insights from professionals with direct expertise.

To capture a more general maintenance perspective, an area engineer (participant 4) was interviewed to provide a broader perspective on maintenance practices. The interview with an engineering manager (participant 3) broadened the view of the overall technological landscape within a plant and considered the overarching responsibilities of a person in this role. A second interview with a reliability

² In an industrial environment, it is common to refer to the employees of the production departments as customers of the maintenance or reliability engineering department.

engineer (participant 7) and a subsequent interview with a maintenance manager (participant 5) helped to round out the overall understanding.

Further participants with relevant qualifications were interviewed in order to achieve saturation and increase the depth of the findings, including a head of engineering (participant 13) who has brought a further perspective to the maintenance and reliability engineering process. In addition, the interview with a maintenance excellence specialist (participant 8) provided a different perspective and added to the diversity of the data collected. The inclusion of a mechanical maintenance manager (participant 14) brought in a focused view of the mechanical maintenance environment, which refined the overall picture. To expand the overall picture, a further interview was conducted with a maintenance manager (participant 15). In order to ensure a well-rounded view from the customer area, a second production manager (participant 16) was interviewed.

The final interview with a works engineer (participant 6) aimed to provide an overarching view of the activity area and consolidate the various findings from the interview sequence.

Table 10: Participants of the study (anonymized). Please note that the participant number does not reflect the order of the interviews.

Participant number	Job description	Country	Sector	Site size	Company size	Language
1	Reliability engineer	Germany	Chemical industry	large	large	English
2	Reliability manager	Germany	Chemical industry	large	large	English
3	Engineering manager	United Kingdom	Chemical industry	medium	large	English
4	Area engineer	Germany	Chemical industry	large	large	German
5	Maintenance manager	Finland	Energy industry	medium	large	English
6	Works engineer	Italy	Chemical industry	medium	large	English
7	Reliability engineer	United Kingdom	Chemical industry	medium	large	English
8	Maintenance excellence specialist	United Kingdom	Food industry	large	large	English
9	Reliability engineer	Germany	Chemical industry	large	large	English
10	Production manager	Germany	Chemical industry	large	large	English
11	Director maintenance & engineering	Germany	Chemical industry	large	large	English
12	Reliability manager	Spain	Chemical industry	medium	large	English
13	Head of engineering	United Kingdom	Food industry	large	large	English
14	Mechanical maintenance manager	Germany	Rolling mill industry	large	large	English
15	Maintenance manager	Germany	Aluminium milling industry	large	large	English
16	Production manager	Germany	Building Materials industry	small	large	English

The point at which theoretical saturation occurred during the qualitative expert interviews is described in more detail in sub-chapter 5.3.8 - Theoretical Saturation.

5.2 TOOLS FOR MAIN STUDY

5.2.1 Interview Guide and Consent Form

The interview guide plays a key role in the interview process, offering essential information that is especially relevant to the interviewee regarding the interview's context and framework conditions, as pointed out by Kaiser (Kaiser, 2014). It serves as a guiding tool throughout the qualitative, spoken data collection phase and serves several vital functions. The guide aids in narrowing down and focusing on specific themes. It also compiles a comprehensive list of all key topics that should be addressed during the interview, thereby enhancing the comparability of collected data through thematic alignment. Furthermore, it plays a crucial role in structuring the communication process, as highlighted by Misoch (Misoch, 2019).

According to Patton, an interview guide goes even further by listing the questions that require clarification during the interview. Its primary purpose is to ensure that uniform fundamental questions are pursued with each interviewee (Patton, 2015). Notably, its development marks the initial step in the execution of expert interviews, a point emphasized by Kaiser (Kaiser, 2014). It is worth noting that the interview guide should ideally strike a balance—avoiding excessive detail and an overwhelming number of questions, as advised by Kaiser (*ibid.*). In addition to considering the dialogue's structure, it is imperative to consider the possible feelings of the participants during the conversation, as suggested by Morgan and Hoffman (Morgan & Hoffman, 2018). The interview guide can be found in Appendix 8.6, encompassing the following sections: preliminary remarks, the interview's procedural aspects, language preferences, the interview consent form, the interview questions themselves, and finally, closure and farewell.

Within the interview guide, the interviewee is informed about the survey's purpose and the universities supporting it. Details regarding the expected duration of the interview and the communication languages are also provided. English is specified as the primary interview language, although German is available upon

request. Additionally, the interview consent form is discussed before the interview questions are presented. A farewell marks the closure of the interview.

It is customary to include specific protocols for informed consent in interviews. These protocols ensure that participants fully understand the context and purpose of the information collection process. They typically encompass several key elements, which Patton outlined:

Firstly, the purpose of gathering information is clarified. Participants are informed about why their input is being sought and what objectives the data collection aims to achieve.

Secondly, the intended audience for the collected information is identified, along with an explanation of how the data will be utilized. This step helps participants grasp the broader context and potential impact of their contributions.

The content of the survey is also disclosed to participants. They are made aware of what specific questions and topics will be covered during the interview, providing a clear picture of the conversation's scope.

Addressing how responses will be managed is another crucial aspect. Participants are informed about the handling of their answers, including details about confidentiality measures to safeguard their privacy.

Additionally, participants are briefed on any potential risks or benefits associated with their involvement in the interview. This step ensures that they are fully informed and can make informed decisions regarding their participation (Patton, 2015). The topics mentioned above have been incorporated into the consent form for the current survey. Notably, the consent form strongly emphasizes guaranteeing absolute confidentiality and anonymity for participants. It also empowers participants by explicitly stating their right to terminate the interview at any point if they wish to do so.

For reference, the interview consent form is included in Appendix 8.5.

5.2.2 Questionnaire Creation

The questions in the questionnaire are derived from the detailed research question and sub-questions. The questions are presented in chapter 5.3.4 - Determination of Questions for Main Study. The initial questions about the person serve

as "icebreakers" or "warm-up" questions. These concerns the respondents personally but are easy to answer to maintain or even increase the respondents' motivation to continue participating (Porst, 1998). The questioning process's logic is structured to be easy for the respondent to understand. Questions on the same topic are grouped into blocks of questions (*ibid.*). The six different blocks of this interview consist of one to six questions. All questions are intended as guidelines for the interviewer to follow. By pre-defining the subjects to be investigated, interviewing several people is made more systematic and comprehensive (Patton, 2015). In line with the principle of openness, it must be acknowledged that deviations from the guidelines should be explicitly allowed in the interview context, such as by asking follow-up questions that were not originally planned (Kaiser, 2014). The final question allows participants to make any additions to the previous questions.

Whether to use open-ended or closed-ended questions had to be considered. First of all, there is a fundamental difference between questions formulated as closed or open questions. With open questions, the interviewee must formulate his or her own answer. In the case of closed questions, the interviewee is given a choice of alternative answers (Schumann, 2012). The use of open-ended questions allows interviewees to speak as they feel comfortable. The disadvantage is, among other things, that the results depend very much on the participant's ability to verbalize and not necessarily on his or her actual attitude towards the questioned issue (Porst, 1998). Open questions, i.e., those without a fixed answer, must be coded after the survey (Kuckartz, 2014a). This makes it possible to compare the answers. Likewise, Porst explicitly points out the considerable effort this entails (Porst, 1998). It should also be considered that open questions have a different quality in terms of content than closed questions, even if the subject matter of the questions is identical (Schumann, 2012). Open-ended questions are also helpful when the possible answers are known in principle but are incredibly numerous and when it is not known which answers will actually be given (*ibid.*). Roulston and Choi describe that in qualitative interviews, open rather than closed questions are typically used (Roulston & Choi, 2018).

The formulation of closed questions presupposes that the possible answers are known. If, in contrast, the possible answers are unknown or not entirely known, it is advisable to formulate the question in open-ended terms (Schumann, 2012). It should also be noted that closed questions are quicker to process. However, one of

the disadvantages of closed questions is that interviewees often do not find themselves in the given categories (Porst, 2014). Arguments such as saving time by simplifying and speeding up the processing of responses cannot be used here. Participants in the study should explicitly report their experiences. Therefore, this study is conducted exclusively with open questions. Only so do the interviewees have the opportunity to answer freely, openly, and uninfluenced by predetermined answers.

5.2.3 Pretesting

In scientific research, pretesting is a necessary matter. The pretest is primarily intended to test the draft interview guide, the response reactions, and the moderator's behavior (Misoch, 2019). However, pretesting in qualitative research is often integrated into the research process. That is, problems with data collection are corrected in later phases of the usually iterative research process. This can be done, for example, by adding more questions to a guideline or by taking further measures. This approach is particularly advantageous for new subject areas because a successive step-by-step approach is possible (Baur & Blasius, 2019).

Nevertheless, this was not the approach adopted in the present study. The interview guide with the pre-prepared questions was checked in a simulated interview situation. In addition to the questions, the preliminary talk and the follow-up talk were simulated, as was the interview consent form, which was also filled out and discussed. The online technology used to conduct the interview, the recording device, and the transmission were also tested. Due to the pretest that was conducted, it was not necessary to adjust the questions during the course of the interview. The recorded pretests were excluded from the evaluation.

The pretest was conducted with two people from the respective expert group. From the perspective of the expected number of participants in the survey, a pretest with this number of participants is sufficient. Weichbold states that even a small pretest is more beneficial than having no pretest (Weichbold, 2019).

The test participants suggested minimal improvements to the questions. These changes were incorporated into the interview guide before the actual start of the interviews. The recording device and the online conference program worked flawlessly.

5.2.4 Technical Equipment

The expert interviews were conducted using a commercially available smartphone, specifically the Apple iPhone 8, which had a recording function. These interviews took place online, utilizing the Microsoft Teams conferencing software. This choice was made for several reasons. Firstly, the software is accessible to all participants at no cost. Additionally, it is widely familiar to most participants due to its common professional use. Its user-friendly interface eliminated the need for participants to deal with complex technology, ensuring a smooth process.

Moreover, the software offered secure data transfer, a crucial consideration for maintaining the confidentiality of the interviews. The ongoing global COVID-19 pandemic prevented in-person meetings, making online conferences the only viable option. Despite the international composition of the participant group, no travel was required, resulting in time savings and a positive contribution to environmental conservation. Following the interviews, the sound files were encrypted and securely stored on the author's laptop computer.

Transcription was carried out using the "Voicedocs" computer program developed by Voicedocs Software GmbH, based in Cologne, Germany. This software is user-friendly, requiring a brief initial training period for proficiency. For the subsequent coding and analysis of the transcripts, we employed the MAXQDA 2022 software from VERBI Software GmbH, headquartered in Berlin, Germany. This well-established program is widely recognized and frequently utilized in research endeavors.

5.3 REALIZATION OF THE MAIN STUDY

5.3.1 Quality Criteria

Flick describes how the question of determining the quality of qualitative social research has been under discussion in qualitative research since the 1960s. This is partly because, unlike in quantitative research, there are no uniform, generally accepted criteria (Flick, 2019). Misoch also describes the suitability of the three quality criteria (objectivity, reliability, and validity) for quality assurance of quantitative research as controversial because these criteria cannot be applied directly to

qualitative research (Misoch, 2019). According to Bortz and Döring, these concepts can be applied in a modified form in qualitative research (Bortz & Döring, 2006).

Objectivity means interpersonal consensus. Thus, different researchers must be able to arrive at comparable results when investigating the same facts using the same methods. This requires an accurate description of the methodological procedure and standardization. The researcher's objectivity does not prevent the interviewees' subjective worldview from being captured (Bortz & Döring, 2006).

Whether qualitative survey techniques should be "reliable" is disputed (Bortz & Döring, 2006). The criterion of reliability cannot be applied to qualitative research without redefinition. It is nearly impossible to conduct an interview identically. Therefore, data reliability plays a different role in qualitative research than in quantitative research. The emphasis here is not on replication but rather on assessing the reliability of the data. Reliability is interpreted as the stability and consistency of the data collection process. Testing the reliability of qualitative data is done by transparently presenting the entire research process. This starts with the study design and continues with the data analysis after the survey has been completed (Misoch, 2019). An essential prerequisite of reliability is that the measured characteristics are stable over time. Thus, repeated interpretations of texts should come to the same conclusion. Reliability, therefore, also plays a vital role in qualitative social research. In qualitative research, the method's reliability is determined (Brühl & Buch, 2006).

Bortz and Döring explain that validity is the essential quality criterion of data collection in qualitative and quantitative research (Bortz & Döring, 2006). In qualitative social research, validity is described as social discourse and the construction of knowledge to achieve trustworthiness. Due to the openness of qualitative social research, there is greater flexibility in data collection. This allows for precision in the results. Thus, misunderstandings can be reduced, which would lead to a distortion of the results and, thus, to lower trustworthiness (Brühl & Buch, 2006).

The assessment of quality for the present work is challenging because there are no uniform criteria to define it (Flick, 2019). Not infrequently, these criteria even contradict each other. The literature offers more suggestions than generally recognized rules. Occasionally, the claim is made that qualitative research should at least

take into account the aspects of reliability, validity, and objectivity. Nevertheless, applying the corresponding criteria from quantitative research to qualitative research is generally rejected (Flick, 2019). Lamnek and Krell emphasize that qualitative researchers collect information in the social field, whereby the participants disclose this information voluntarily. They have the freedom to formulate and interpret their information freely without any guidelines from the researcher. In contrast, quantitative research problems result from the lack of congruence between theoretical categories and the real world, which in turn leads to questions regarding methodological quality criteria. Such challenges are not present in the same way in qualitative social research due to a different approach to data collection and theory construction (Lamnek & Krell, 2016).

This qualitative study was conducted in accordance with the established scientific guidelines, including recording, processing (in particular, transcription and coding of the data), and analysis. Misoch states that the reliability of a study can be considered as given if all the steps carried out in the scientific process have been described in detail (Misoch, 2019), which is the case in this thesis.

5.3.2 Ethical and Legal Aspects of Interviewing Experts

Interviewing experts introduces a unique and potentially unfamiliar situation for these persons, one they willingly engage in due to their genuine interest in the research. This motivation often stems from their awareness of the significance of their respective fields of work or other personal reasons (Kaiser, 2014). In research ethics, a fundamental and non-negotiable principle is safeguarding the well-being of individuals participating in social science studies. As emphasized by Gläser and Laudel in 2009, the overarching ethical imperative is to prevent any harm to the participants (J. Gläser & Laudel, 2009). In order to adhere to this ethical guideline, it is essential to give participants the opportunity and autonomy to decide about their participation. In this context, participants can terminate the interview whenever necessary. This assurance empowers them to exercise control over their participation and prioritize their comfort and well-being throughout the research process. This approach aligns with ethical principles and fosters mutual respect and trust between the researchers and the experts being interviewed.

In research ethics, researchers must follow principles that govern their conduct, ensuring the highest standards of ethical behavior throughout the research process. However, beyond ethical considerations, there exists a baseline of legal standards that must be followed in nearly every country across the globe. These legal requirements serve as a fundamental framework to ensure that research activities are conducted within the boundaries of the law. In the specific context of this research, which takes place within the European Union, a dual legal framework must be observed. Firstly, the laws and regulations of the European Union itself must be followed. The General Data Protection Regulation (GDPR) enacted in 2016 is a vital cornerstone of these regulations (General Data Protection Regulation, 2016). The GDPR sets comprehensive guidelines for protecting and handling personal data, which are of principal importance in research involving human subjects. Secondly, as this research is conducted within the Federal Republic of Germany, the legal framework of this nation also comes into play. The German Bundesdatenschutzgesetz, or Federal Data Protection Act (BDSG), is particularly relevant in this context (Bundesdatenschutzgesetz (BDSG), 2021). The BDSG is aligned with the GDPR and further refines data protection regulations following the European Union's directives.

By observing both the GDPR and the BDSG, researchers in this scenario meet the minimum legal standards and demonstrate a commitment to data privacy and ethical research practices. This dual adherence ensures compliance with the law and upholds the rights and protections afforded to research participants in both the European Union and Germany. It highlights the significance of conducting research that respects the legal and ethical frameworks established to safeguard individuals' rights and privacy.

5.3.3 Ensuring Ethical Standards and Privacy

As defined by Kaiser, personal data covers any information that offers insights into an identifiable individual's personal and material circumstances (Kaiser, 2014). This definition aligns with the German Federal Data Protection Act, which provides a more detailed perspective. In this context, personal data refers to all data points associated with a person who can be identified, either directly or indirectly. Indirect identification occurs when an identifier is linked to an individual, and these identifiers can encompass a wide range of information, such as a person's

name, identification number, location data, online identifiers, or other distinctive characteristics (Bundesdatenschutzgesetz (BDSG), 2021).

Direct identification is relatively straightforward and occurs when the data alone is sufficient to identify a specific individual. For instance, knowing someone's full name or unique identification number can directly identify them. Indirect identification involves using additional information or context to single out an individual. This can be achieved by combining seemingly harmless pieces of data to unveil a person's identity. Therefore, even anonymous or unrelated data can become personal data when it is possible to deduce the identity of the person to whom it pertains. Therefore, personal data should not be collected or processed, even in research settings, unless it is essential for the stated research purpose. This principle aligns with the broader ethical and legal framework governing data protection and privacy (Kaiser, 2014). It emphasizes the importance of minimizing the collection and use of personal data to only what is essential and justified by the research objectives.

Informed consent is a fundamental ethical principle in research, emphasizing the researcher's responsibility to ensure that participants are fully aware of the study's purpose and content (Kaiser, 2014). It goes beyond a mere formality and involves a comprehensive process to safeguard the rights and well-being of those involved. The significance of informed consent in sociological research is reinforced by a 2013 publication from the European Commission. It emphasizes that informed consent and confidentiality principles are as essential in sociological studies as they are in clinical research. These principles safeguard participants' rights, dignity, and privacy, regardless of the study's nature. This also brings attention to three key elements: providing adequate information, ensuring voluntariness, and assessing competence (European Commission, 2013).

Adequate information means that participants must be thoroughly informed about the research's objectives and what it entails. This includes clearly explaining what the study aims to achieve and what participants can expect during their involvement. Additionally, potential undesired events or risks associated with participation should be transparently communicated. Participants should have a complete understanding of what they are getting into, enabling them to make an informed decision about their participation.

Likewise, voluntariness is a crucial aspect of informed consent. Participants must willingly agree to participate in the study without any form of coercion or pressure. They should be aware that their participation is completely voluntary, and they can decline or pull out of the study at any point, even after the interview. This ensures that individuals are not compelled to participate against their will and can exit the study if they become uncomfortable or no longer wish to continue.

Lastly, the third component of informed consent is competence. It is crucial to evaluate whether participants have the cognitive and emotional capacity to make an informed decision about their participation. This involves ensuring that participants understand the information provided, weighing the risks and benefits, and making a rational choice regarding their involvement (European Commission, 2013).

To adhere to these principles, researchers must engage in a thorough dialogue with potential participants. All steps of the research process, including its objectives, potential risks, and the option to decline participation or withdraw at any time without consequences, should be clearly and comprehensively explained.

Confidentiality and anonymity are important principles in social research, serving as promises and guiding concepts for researchers when dealing with their study participants. Although these two concepts are often discussed together, they have distinct focuses (Tiidenberg, 2018). Confidentiality primarily concerns safeguarding information that would otherwise be kept secret (European Commission, 2010).

In the specific research context described, all participants in this study were given explicit assurances of strict confidentiality and anonymity prior to their participation. These assurances extended to handling confidential personal data necessary for conducting interviews, with access restricted solely to the person conducting the study. This sensitive information included participants' names, their affiliated organizations, and the exact employee counts at the interview location and within the broader company or corporation. To enhance security, the study's author securely stored this personal data in encrypted form. It is important to note that any additional personal information volunteered by participants before or after the interview was not recorded in written form, ensuring an extra layer of

protection. Personal details were meticulously anonymized during the transcription of interview recordings, emphasizing the commitment to preserving anonymity. To further guarantee the security and compliance of these practices, the author stored non-anonymized audio recordings in encrypted form, aligning with the applicable German legislation on data protection, particularly the Bundesdatenschutzgesetz (BDSG) (Bundesdatenschutzgesetz (BDSG), 2021). This legal framework necessitates anonymizing personal data as swiftly as possible for research or statistical purposes. While this anonymization requirement may be in place, it does not hinder the ongoing research. The assumption is that expert knowledge is independent of the individual in a certain sense. Professionals with considerable experience in a specific field often generalize their knowledge, presenting it in a way that goes beyond personal and highly individual traits (Helfferich, 2019). These measures adhere to ethical standards and legal obligations, safeguarding the security and integrity of the research endeavor while enabling the valuable extraction of expert knowledge from the participants.

5.3.4 Determination of Questions for Main Study

The literature review and the descriptive quantitative preliminary study are essential components of the research process, providing a deeper understanding of the topic at hand. However, they are not sufficient on their own to fully address the complexity of the research question and its sub-questions. Therefore, a qualitative study was conducted as the primary step, with careful and intentional focus placed on the design of the questions.

The questions for the main qualitative study were deliberately and strategically developed by the author to ensure that they provided a comprehensive answer to the research question and its sub-questions. When selecting questions for the experts, care was taken to follow a targeted approach. The questions were designed not to elicit simple, straightforward answers but to encourage the experts to share their extensive knowledge and insights. The primary goal was to capture the experts' in-depth information, experiences, and perspectives. The deliberate framing of the questions was intended to stimulate a broad conversation and exploration of the topic. This approach allowed for a holistic perspective that not only provided superficial answers but also allowed for a more informed and conclusive answer to the research question.

The following sections and questions were derived from this:

Section 1 – Basics/Organisation

The interview begins with an introductory phase. This phase serves several vital purposes. First, it is intended to create a pleasant and inviting atmosphere and ensure the interviewee feels comfortable and ready to engage in the conversation. Second, it helps to transition smoothly into the primary interview. This phase begins by asking about the interviewee's current job position. This first question serves as a simple icebreaker, allowing the interviewee to share some information about their current role that can provide valuable context for the rest of the conversation. This is followed by a question about the interviewee's previous professional experiences. The interview becomes more personal and engaging by elaborating on previous positions and the applicant's career history. This step allows the interviewees to reflect on his or her careers and provide insights that may be relevant to the main topic of the interview. The final component of the introduction is to ask the interviewee about his or her involvement in the field of reliability engineering. This question serves as a bridge to the core topic of the interview. It allows the interviewees to share their experience and expertise in this field, and it also helps gauge their familiarity with the topic. This information was equally critical to assessing their level of experience and expertise. It made it possible to distinguish between individuals who were relatively new to the field and those with years of experience, which ultimately ensured a diversity of perspectives.

- a) In which position do you work?
- b) If relevant: In which positions were you previously employed?
- c) How long have you been concerned with the topic of "reliability engineering," and in what context?

The preliminary survey provided some basic information about the organizational structure of the maintenance departments and REDs in each company. While the preliminary quantitative survey allowed for basic questions to be asked, it was limited in its ability to capture the intricate details and nuances of the organizational structures within these companies. The preliminary survey also aimed to understand how participants perceived the need for potential adjustments to the existing organizational structure.

However, a more in-depth approach was needed to provide a comprehensive and conclusive answer to the research question. The preliminary survey only scratched the surface of the topic. Further questions and research were needed to understand better the maintenance department's and RED's organizational structure and potential for improvement. These questions should delve deeper into the particulars of the organizational structures and potentially address aspects such as strategies, practices, reporting lines, decision-making processes, communication flow, and the impact of these aspects on the efficiency and effectiveness of the maintenance department and the effects on the overall company structure. Such a comprehensive investigation provides a more precise and more insightful perspective on the topic. These questions were particularly important as they provided insight into the real-world implementation of reliability engineering within different organizational structures. If the participants feel areas within the company's maintenance structure need to be improved or adapted, these should be explicitly addressed. The experts could outline potential changes they would make to their maintenance organization.

d) How is your maintenance organization structured, and how is reliability engineering integrated there?

e) If required for in-depth study: What should the maintenance organization look like from your point of view – especially with regard to the reliability engineering department?

Section 2 – Reasons why companies want to implement a reliability engineering department

The primary objective of the preliminary study was to determine whether the participating companies had already established a RED. This simple binary question aimed to provide a clear "yes" or "no" answer regarding the existence of such a department in the companies surveyed. This question aimed to establish a basic understanding of the prevalence of REDs in the interviewee companies. However, the causes for the absence of a RED in the company were not addressed. This omission warrants further investigation. Aside from possible financial constraints, the preliminary survey did not explore the motivations of companies adopting a RED. To gain these insights, the following questions are asked. Likewise, the participants were asked to shed light on what, if anything, is holding a company back from

implementing a RED. In addition, participants were asked to provide a general assessment based on their understanding of reliability engineering and then relate that assessment to their own company. Equally, the question of what motives are behind introducing REDs in industrial companies was investigated. The question was intended to clarify whether these motivations are the same in different organizations. It was essential to find out if a common set of factors drives companies toward reliability engineering.

f) Does your site/company already have a stand-alone reliability engineering department?

g) If no: Do you intend to introduce such a department soon?

h) If no: Why not?

i) Why do you think more and more companies are introducing a stand-alone reliability engineering department?

j) If yes to questions f) or g): Are these also the reasons why you already have or intend to introduce such a department?

k) Are these the only reasons, or are there any others?

Section 3 – Expected savings through the implementation of a reliability engineering department

This section focuses on delving into the questions about expected and realized savings resulting from implementing a RED. In the preliminary quantitative survey, questions primarily revolved around commonly recognized savings opportunities, such as cost reductions in maintenance and related areas. However, these initial inquiries revealed only a highly narrowed area of potential cost savings that could be associated with a RED. Given the complexity of cost-saving strategies, it is highly likely that companies will have additional, more specific expectations of a RED beyond general reductions in maintenance costs and the like. This section aims to uncover and fully explore these additional expectations, particularly regarding qualitative factors. Beyond identifying these expectations, the survey will also examine whether these expected savings have been realized. This aspect is critical because actual results may differ from initial expectations. By assessing the extent to which these savings targets have been met, the survey will measure the effectiveness of REDs in practice.

However, the survey goes a step further by asking the reasons for any discrepancies between expected and achieved savings. In cases where expected savings have not been fully realized, it seeks to uncover the underlying factors that have impeded the achievement of these savings targets. This survey could cover various potential issues, such as operational challenges, resource constraints, or unexpected market changes, and is intended to provide valuable insight into the practical challenges companies face in optimizing their reliability engineering efforts.

l) What types of improvements and savings do you expect from implementing a reliability engineering department?

m) Can you quantify these expected improvements and savings (e.g., as a percentage to the maintenance budget or in actual totals)?

n) Have these improvements/savings been achieved in the past?

o) If no: Can you say why not, and in what time frame do you think the savings will be achieved?

Section 4 – Evaluating the effectiveness of a reliability engineering department

The preliminary study laid the groundwork for understanding certain quantitative aspects of measuring a RED's effectiveness. This phase allowed for the collection of numerical data, which could provide insights into some of the primary metrics and outcomes associated with REDs. However, it had inherent limitations, as it could not comprehensively address the more extensive and far-reaching aspects of RED effectiveness. Recognizing the need for a more thorough examination of the effectiveness of REDs, this part of the interview explicitly focuses on investigating the methods used to determine their impact and effectiveness. This represents a deliberate shift beyond the exploration of numerical outcomes to the broader and qualitative dimensions of the impact and benefits of REDs on organizations. By explicitly inquiring about the methods employed to gauge the impact of REDs, the study aims to uncover the various approaches, tools, and indicators that companies utilize to measure the department's effectiveness. Understanding the methods for evaluating these aspects provides a more complete perspective on how REDs contribute to a company's overall success.

p) How do you track the efficiency of the reliability engineering department?

q) Which Key Performance Indicators (KPIs) do you use?

r) Are there any other aspects that you use to see or measure effectiveness? Please elaborate if this is applicable.

Section 5 – Achievable savings through a separate reliability engineering department compared to a conventional setup

The preliminary study was limited in its ability to provide a comprehensive and summary overview of the advantages and disadvantages of companies that have a RED compared to those that do not. This vital aspect of weighing benefits against costs was not addressed concisely. The final contextual question aims to get participants to provide a comprehensive analysis of the advantages and disadvantages of having a RED in their organization compared to organizations that do not have one. They are asked to elaborate on the specific advantages they perceive in relation to all relevant factors.

s) Taking all costs into account, what do you think are the particular advantages of a stand-alone reliability engineering department?

Section 6 – Concluding Remarks

In conducting a qualitative survey, it is important to allow participants to express their thoughts, opinions, or insights more freely and without constraints. The final question in the survey serves this vital purpose by allowing participants to expand on their previous responses, dig deeper into the topics discussed, or share any additional comments they deem relevant. It enables them to clarify their responses, provide context, or offer more detailed explanations regarding their choices. Furthermore, the final question invites participants to express their thoughts beyond the specific survey items. This open space for comments promotes a deeper and broader understanding of the topic and offers a more comprehensive view of the participants' perspectives.

t) Would you like to add to or elaborate on any of the questions?

5.3.5 Consent Form and Interview Guide Application

In ensuring the protection of both participants and the interviewer in this research, a crucial step was taken by implementing a comprehensive consent form

procedure. As Patton highlighted, this practice aligns with established research ethics guidelines and protocols (Patton, 2015). Before each interview, the interviewer took the initiative to introduce and discuss the consent form with the participants. This served the purpose of informing the participants about the consent process and reaffirming their voluntary participation in the study. This protocol was in line with best practice. To further emphasize the importance of clear communication and transparency, the interviewer revisited the content of the consent form at the outset of each interview. This repeated the participants' expectations and rights, ensuring they were fully aware of their involvement and ability to withdraw from the study at any point. As an added measure of accessibility and to facilitate ongoing communication, the interviewer's contact details were provided within the consent form. This allowed participants to ask questions or express their concerns, even after the interview.

Each participant received a copy of the interview consent form well before the interview. They were then requested to carefully review, sign, and return the form to the interviewer before the interview. This practice ensured that participants had ample time to understand the implications of their participation but also reaffirmed their voluntary agreement to partake in the research.

The interview consent form was designed to provide participants with comprehensive information about critical aspects related to the confidentiality and utilization of their data. This approach allowed participants to ask detailed questions and seek clarification on any concerns they might have had before the interview commenced. Doing so maintained a high standard of ethical conduct throughout the research process. Importantly, the interview consent form also served as a tangible record of the participants' approval to participate in the study. To preserve the integrity of this process, all signed consent forms were securely stored electronically in an encrypted form by the author. This stringent data security measure ensured the privacy and confidentiality of participant information.

For reference and transparency, a blank interview consent form has been included in Appendix 8.5 of this research documentation.

A critical step in ensuring transparency and participant engagement was providing the interview guide to each participant before the actual interview took

place. This practice was implemented as part of the commitment to upholding ethical research standards and promoting participant autonomy. The preemptive sharing of the interview guide was also a proactive measure to enhance the quality of the data collection process. It also allowed participants to familiarize themselves with the upcoming interview's structure, content, and objectives. Notably, some participants specifically requested to receive the interview guide beforehand, underlining their keen interest in being well-prepared for the interview process.

The interview guide itself served as a comprehensive resource for the participants. It included the complete set of interview questions that would be asked during the interview and a concise summary of the interview process. This summary covered the expected interview duration, the general flow of questions, and any additional information that might be relevant for participants to know before the interview session.

For reference, the complete interview guide used in this research has been included in Appendix 8.6.

5.3.6 Data Collection and Interview Setting

Recruiting participants for this study began on November 18, 2021, and followed a well-structured approach. In total, 21 individuals were initially approached in three distinct phases. However, due to several factors, such as time constraints or personal commitments, five individuals initially contacted could not participate in an interview for this research project. The expert interviews were conducted between November 23, 2021, and January 04, 2022. It is important to note that this research deliberately did not plan for multiple interviews with the same participants. Instead, each expert was interviewed only once during the study. The interview process was comprehensive and tailored to the specific circumstances, with participants being asked 14 primary questions and six in-depth questions derived from the interview guide. These interviews were conducted precisely, with all responses and interactions being digitally recorded as audio files during the scheduled appointments.

The implementation framework for conducting interviews is vital to the research process. The primary goal is to ensure that the interviewed individuals feel

at ease and comfortable enough to share the details of their experiences openly. This approach is crucial in obtaining rich and valuable information from the interviewees, which can be instrumental in conducting meaningful research (Murray, 2018). One key element of this framework is for the interviewer to exhibit a genuine interest in the subject matter and to convey a certain level of empathy towards the interviewee. Doing so makes the interviewee more likely to feel heard and understood, which can foster a more productive and insightful conversation.

It is important to acknowledge that interview settings are inherently artificial regardless of how well crafted. Researchers design these environments to gather specific data and insights (Morgan & Hoffman, 2018). Despite their artificial nature, interviews are dynamic and fluid interactions. They tend to take on a life of their own as the conversation unfolds. As a result, the interviewer and interviewee's initial expectations may evolve throughout the interview (Trinczek, 2009).

Nonetheless, researchers must make a concerted effort to create an environment conducive to asking the selected questions. This typically involves ensuring participants are interviewed in a familiar space, such as their home office or workplace. This familiarity can contribute to a sense of comfort and ease, improving the quality of the information shared during the interview.

5.3.7 Conducting the Interviews

In conducting interviews for this study, a systematic and standardized approach was followed, ensuring consistency and reliability throughout the data collection phase. The interviews were conducted using Microsoft Teams, an online communication platform that facilitated both video and audio transmission, enabling effective interaction between the interviewer and the interviewee. The interview process was structured into distinct phases to ensure a comprehensive yet flexible approach. Initially, a preliminary discussion was held with each participant. During this phase, the interview procedure and data protection measures were thoroughly explained, establishing a transparent and ethical foundation for the interviews. Participants needed to be fully aware of the process and their rights in terms of data privacy. Following the preliminary talk, the central part of the interview was conducted. This phase involved posing questions from the interview guide designed for the study. These questions served as a framework for the conversation, ensuring that key topics were covered systematically. However, it is

essential to note that these questions were not rigid constraints but instead acted as guiding points. The interviewees were free to delve deeper into specific topics or introduce additional insights relevant to the research. Likewise, the interviewers had the flexibility to ask follow-up questions to enhance their understanding of the responses. This adaptability was vital to capture the richness and depth of the data.

Kaiser's principle of openness was applied during the interviews, allowing for deviations from the predefined guidelines when necessary. This flexibility was beneficial for accommodating follow-up questions or addressing unexpected but pertinent issues that arose during the conversations. It emphasized the importance of responsiveness to the interviewee's input, enabling a more natural and fruitful dialogue (Kaiser, 2014).

However, it's essential to highlight that any modifications or extensions to the provided questions were made cautiously and only when necessary for better comprehension. The goal was to balance adaptability and consistency to ensure that the data collected remained comparable and evaluable across all interviews. This approach aimed to yield comprehensive insights while upholding the integrity of the research process. In addition, the audio recording of each interview was initiated with the commencement of the first question and concluded after the farewell. This practice ensured that all interactions were accurately documented while respecting the interviewee's informed consent regarding the recording's initiation and termination.

5.3.8 Theoretical Saturation

Saturation involves accumulating comprehensive data during the inquiring process, focusing on the extent of coverage and recurrence, thus contributing to developing theoretical dimensions within the research (Morse, 2015).

This section deals with the implementation and the onset of theoretical saturation. Fundamental information on this concept can be found in Chapter 5.1.2 - Sample Size and Theoretical Sampling.

Achieving theoretical saturation doesn't imply that there are no more participants to interview (or data to gather). Still, additional interviews (or data) will no longer contribute significant new insights to the theory developed from the data collected up to that point. Saturation in this context is not determined by the

number of interviews but by the richness and depth of the insights provided by the data that has already been gathered and analyzed. (Flick, 2022). The steps presented below, such as transcription and coding, must occur in parallel with the expert interview to ensure that the onset of theoretical saturation is recognized in time. After ten experts had been interviewed, transcription was completed for these participants, and an initial coding of the same was carried out. Subsequently, the coded elements were summarized, and the content was reviewed. In the coding examined, the results appeared not to be sufficiently consolidated.

It could be reasonably assumed that further realizations would still be found in the respective categories. As a result, it was decided to interview further participants. After every new participant, the interview was transcribed, and the coding was carried out. The process of testing the theoretical saturation followed this. After interviewing six more experts, i.e., a total of 16 participants, it showed that saturation had occurred in the categories under consideration.

Only minor changes to the reviewed statements were made after ten experts were interviewed. Here, it was not to be expected that further major changes could be found in the participants' statements.

Three codes are presented in more detail here as examples of how to achieve theoretical saturation. These three deliberately randomly selected codes are not a prioritization of the codes in any way but are merely intended to illustrate the process of saturation. The same procedure was followed for all other codes:

(1) IQS - Improvements and savings quantified: The justification for using theoretical saturation from this data lies in the recurring focus on cost reduction, particularly in maintenance budgets and production losses. Multiple instances mention cost reduction percentages achievable through improved reliability, ranging from 5% to 15% or even higher depending on the company. These repeated references to percentage-based improvements in maintenance budgets and production losses demonstrate a constant theme within the data. Additionally, there are mentions of specific monetary savings achieved through reliability improvements, such as millions of euros or thousands of tons of production. These concrete examples underscore the financial impact of reliability and contribute to the data's thematic consistency.

Furthermore, the data emphasizes the importance of improving preventive maintenance execution and overall equipment efficiency (OEE) as means to achieve these cost savings and production improvements. These concepts are reiterated throughout the data, reinforcing the central theme of reliability's role in cost reduction. In summary, the recurring percentages, monetary figures, and references to cost reduction and production improvement establish a dominant thematic pattern that justifies the use of theoretical saturation, as further data collection is unlikely to yield substantially different insights regarding the financial benefits of reliability improvements.

(2) PRR- Particular reasons for RED: The rationale for employing theoretical saturation in this dataset is rooted in the constant emphasis on the advantages and benefits of having a separate reliability department. Multiple instances discuss how a standalone reliability team can better focus on resources, avoid distractions, and concentrate on long-term reliability improvements. The data repeatedly underlines the importance of having dedicated personnel who can step back and look at the bigger picture, manage by fact, and work on mid and long-term reliability improvements. Furthermore, the data mentions various specific advantages, including the ability to anticipate future reliability issues, adopt modern maintenance strategies, explore new technologies, and implement condition-based maintenance technologies. The advantages of reducing breakdown rates, improving plant availability, and extending the time between interventions are reiterated throughout the data. A recurring theme of cost savings is associated with having a reliability department, which reduces maintenance costs, optimizes spare parts, and addresses obsolescence issues. Additionally, the data highlights a department's importance in quantifying and comparing costs effectively. The repeated emphasis on these advantages and benefits, along with practical examples and specific advantages of having a separate reliability department, supports theoretical saturation, as gathering additional data is improbable to lead to new insights concerning the advantages of an independent reliability team.

(3) ORI – Integrated (sub-code of ORE – Own RED): The reason for using theoretical saturation becomes apparent when examining the repeating motif found throughout the dataset. Participants frequently describe their maintenance setups, which frequently entail distributing reliability-related responsibilities among various roles within their respective organizations. These roles encompass

maintenance engineers, asset engineers, and similar positions, often lacking the formal designation of a reliability engineer. Although a distinct standalone reliability department is absent, numerous team members within the maintenance teams actively participate in reliability-focused tasks. This melding of reliability functions into the realm of maintenance is explicitly validated by several participants who acknowledge that, despite not explicitly adopting the reliability engineering terminology, their operational processes inherently encompass facets of reliability engineering. Consequently, the dataset emphasized the integration of reliability-related duties within the broader maintenance framework, even without a dedicated reliability department. Thus, the decision to employ theoretical saturation is rooted in the dataset's persistent reinforcement of this blended approach to reliability within maintenance divisions, as it is unlikely that additional surveys of data will provide substantial new evidence of the benefits of an independent reliability team.

5.3.9 Transcription and Data Cleansing

The basis of any investigation of communicative behavior is the recording of the current communication in a form separated from the situation as a documentary transcription (Dittmar, 2004). Most definitions of transcription are based on scientific criteria. The transcription should not only be roughly authentic but should reflect the actual communication situation as accurately as possible (Dittmar, 2004). Through transcription, a complex natural communication event consisting of individuals interacting with each other in an actual situation is mapped one-dimensionally on paper (*ibid.*). Different transcription systems can be used in qualitative social research. The system is selected depending on the research question and the required data depth (Misoch, 2019).

Interviews conducted in German (one in this case) were transcribed in German and then translated into English. Only the English version was used for further analysis. The rules for anonymization outlined in the previous sub-chapters are implemented in the transcription process.

The transcription header precedes the transcription of the interview and contains relevant information about the interview conducted (Misoch, 2019). It represents a kind of "cognitive" bridgehead between the authentic communication situation and the documentation of the reconstructed-simulated event (Dittmar, 2004).

Depending on the research interest, the transcription header can be more detailed or concise. The content may, therefore, vary (Misoch, 2019).

During the transcription process, several bits of information were incorporated and positioned at the start of the actual transcription. This included details such as the participant's identification number, the date when the recording took place, the location of the recording, the interviewer's name, the individual responsible for the recording itself, the transcriber's identity, the duration of the recording, the specific recording device utilized, any noteworthy linguistic peculiarities observed, and any additional transcription-related notes that were deemed relevant.

Linguistic peculiarities primarily indicate the language in which the interview was conducted and whether the participant or interviewer is a native speaker. Table 10 depicts a comprehensive table with additional information about each participant.

The transcription rules determine how the spoken language is transferred into written form. Information loss is unavoidable during the conversion process. Which losses are considered acceptable and which are not depends on the aim and purpose of the planned analysis (Kuckartz, 2018). Gläser and Laudel indicate that the recorded interview should be transcribed as completely as possible (J. Gläser & Laudel, 2009). They further state that the main objection to transcription is the massive amount of time and cost involved. In their experience, the ratio of interview time to transcription time in the literature is 1:4; their personal experience is more like 1:6 (*ibid.*). Misoch even talks about a ratio of up to 1:7 (Misoch, 2019).

To date, there are no generally accepted rules for transcribing interview transcripts (J. Gläser & Laudel, 2009). This has also been confirmed by Kaiser (Kaiser, 2014). However, a variety of rules and systems are named in the literature, which mainly refers to the detailed mapping of nonverbal communication as required for social science studies (Kuckartz, 2018). Relatively simple transcription systems are sufficient for most research projects (*ibid.*). In the present work, however, the aim is to gain professional knowledge. Therefore, it is not necessary to describe nonverbal communication in writing here.

The transcription system employed for the expert interviews is primarily based on the recommendations of Gläser and Laudel, Kuckartz, and Mayring (J.

Gläser & Laudel, 2009; Kuckartz, 2018; Mayring, 2015). The following guidelines were adhered to during the transcription process:

The transcription is conducted literally, without any phonetic representation or summarization. Any existing dialects are not transcribed but translated as accurately as possible into standard language. Language and punctuation are slightly adjusted to approximate written language, and dialect nuances are smoothed out. Repetitions of words are omitted if they do not alter the sentence's meaning. Expressions like "Er" and similar interjections are excluded. Clear and extended pauses in speech are denoted by ellipsis points (...) enclosed in brackets. Agreeing or confirming responses from the interviewer (such as "uh-huh," "yes," "right," etc.) are not transcribed unless they disrupt the interview's flow.

Interruptions are acknowledged within brackets, along with an indication of the cause, for example, (cell phone rings). A dash marks interruptions occurring in the middle of a sentence or word "/." Incomprehensible words are accompanied by a reason for their unintelligibility, e.g., (unintelligible, indistinct). Non-verbal utterances like laughing, clearing the throat, coughing, or stuttering are transcribed only when they decisively alter the meaning of a statement.

The interviewer is identified as "I," and the participant is identified as "P." The commencement of a new paragraph denotes each change in the speaker. Appendix 8.7 ff contains the transcripts of the interviews.

For some years now, a new possibility of transcription has been increasingly discussed: the use of speech recognition software for transcribing verbal data. Speech recognition software refers to computer programs that automatically recognize spoken words and convert them into written form (Misoch, 2019). The automatic transcription of interviews with a corresponding computer program is not yet sufficiently reliable (Kuckartz, 2018). For the transcription task within the scope of this work, the computer program "Voicedocs" was used. However, it turned out that the automatic transcription of the spoken word did not come close to satisfying the quality requirements of the author. All audio files had to be reworked very extensively by hand. A relevant saving of time and work could not be determined. Misoch also discovered this fact (Misoch, 2019).

In the case of external data transcription, the researcher has the duty of care to listen to the entire data set again after transcription and to correct any

discrepancies that arise (Misoch, 2019). Easton, McComish, and Greenberg also point out that the researcher and the transcriber should be the same person. This way, typical problems can be avoided (Easton et al., 2000). In this present work, it was deliberately decided that external help was not used for transcription. In the author's opinion, this does not lead to any time savings. Instead, additional work arises because a high-quality standard must be maintained. Furthermore, the assurances of confidentiality given to the participants could not be kept by an external contractor.

Misoch points out that transcription must be carried out very carefully. Transcription is an elementary component of the quality assurance of qualitative data. Therefore, the transcription process and data management should be part of the research report. This way, the processes can be intersubjectively comprehensible and transparent (Misoch, 2019). Several errors can occur during transcription. The whole meaning of the sentence can be changed if the transcription is inaccurate. The possible errors can be as simple as incorrect punctuation or as severe as misspelled words (Easton et al., 2000). With this in mind, the audio recordings of all carefully finalized transcribed interviews were thoroughly checked for proper translation at least thrice. Subsequently, the written transcripts were rechecked. Dittmar describes that for a good transcription, high-quality sound is necessary (Dittmar, 2004). A digital audio recording ensured this.

Several major steps were taken in the preparation and processing of the data, in addition to the initial data cleaning described in the transcription rules introduced earlier in this sub-chapter. One crucial aspect was ensuring the anonymity of the data. This was achieved by systematically replacing all names mentioned, whether they referred to individuals or companies, with specific placeholders. In the case of names of individuals, "(name)" was used as a substitute, while "(company)" was employed for company names. This meticulous substitution of names was a critical measure to protect the privacy and confidentiality of the individuals and entities stated in the data.

Furthermore, to safeguard the confidentiality of company-related information, any references to the locations of these companies were also rendered unidentifiable. This was accomplished by replacing company locations with "(site)" or "(city)." This approach ensured that even if the data were to be accessed by

unauthorized individuals, the specific geographical details of the companies would remain undisclosed. Besides that, these privacy-related measures, foreign words, or designations encountered in the data were also addressed. These foreign terms were translated into English whenever necessary and were always enclosed in brackets immediately following the original foreign language word. This practice was adopted to enhance the comprehensibility of the data, especially when foreign terminology had not been previously translated during the dialogue or data collection process.

By implementing these comprehensive data anonymization and translation measures, the integrity and confidentiality of the information were diligently safeguarded, allowing for a more secure and accessible handling of the data for analysis and other purposes.

5.3.10 Content Analysis and Coding

Especially in the German-speaking area, qualitative content analysis, particularly in its further development by Philipp Mayring, is frequently used as a standard method for data analysis. Despite its popularity, problems arise repeatedly in the practical application of the method, ultimately due to ambiguities and uncertainties regarding the definitions of terms. The main problem is that partly contradictory explanations of what qualitative content analysis actually entails can be found in the literature (Schreier, 2014). She makes a point by stating that there is no single form of qualitative content analysis and no general agreement on what exactly characterizes qualitative content analysis (*ibid.*).

While Mayring and Rustemeyer see qualitative content analysis as a procedure guided by theories, Kuckartz and Schreier place particular emphasis on the importance of category creation, which can also be derived from the material itself. Gläser and Laudel, on the other hand, basically advocate using a mixture of deductive and inductive approaches in content analytic evaluation (Schreier, 2014).

The analysis in this paper is primarily based on the proposals presented by Kuckartz in 2014 (Kuckartz, 2014b) and together with Rädiker in 2019 (Kuckartz & Rädiker, 2019) and in 2020 (Rädiker & Kuckartz, 2020).

Primary, the coding system presented by Rädiker and Kuckartz was used in six steps :

1. data preparation and exploration
2. development of the category system
3. basic coding
4. further development of the category system and fine-coding
5. analysis of the coded data
6. report and documentation (Rädiker & Kuckartz, 2020)

In the first step, data preparation and exploration, the transcripts were uploaded to the MAXQDA system. All 16 transcripts were included without restriction. Subsequently, the transcripts were examined. The first ten transcripts were examined consecutively. Then, one transcript after another was coded and examined. The goal of this is to become familiar with the texts in order to discover anomalies and patterns. At the same time, the cases are to be considered as a whole without already falling into a categorizing view (Rädiker & Kuckartz, 2020). The specialized literature often states that the collected material can be paraphrased to reduce the volume of transcribed interviews, for example, Kuckartz and Rädiker (Kuckartz & Rädiker, 2019). The MAXQDA software even offers a help function for this purpose. For the present study, paraphrasing of the transcribed interviews was waived for two reasons. First, reducing the textual volume is unnecessary because the transcribed interviews are of a manageable length. Second, the vast majority of the participants answered the questions briefly and precisely. A further shortening of what was said did not seem expedient here.

In the second step, the initial category system was developed based on the interview questions in the interview guide. This system was supplemented with additional codes that arose during the initial exploration of the transcripts, which resulted in an initial system consisting of 15 principal codes and 20 sub-codes.

The third step consisted of basic coding. Each text passage considered relevant was assigned a category. The choice of the item of analysis, for its part, varies. Depending on the individual expert's statement, this can consist of a part of a sentence, a sentence, or several sentences (a paragraph). This system was followed for each transcript. In the case of demarcation problems between categories, the respective category definitions were improved and expanded where necessary.

Statements that expressively describe a fact are also assigned to the category "quotable text passages." In addition, the categories were constantly reviewed and adjusted where necessary. This optimization should start as early as possible (Rädiker & Kuckartz, 2020). Duplicate answers were only coded if necessary for comprehension, e.g., in the case of similar answers to different questions. These may result in different coding. The review of the transcripts was done a total of three times, with some intervals between each review.

This step was followed by further development of the category system and fine-coding, considering all coded segments in the respective base categories individually. Where necessary, categories were merged, refined, or, if required, removed. After completing the fine-coding, 13 principal codes and 13 sub-codes were available. These are shown in Table 11.

Table 11: Codes (final version)

QUA - Qualification	
	QUC - Current position
	QUF - Former position(s)
	QUD - Duration reliability engineering
COO - Current organization	
	COM - Maintenance
	COR - Reliability engineering
OPO - Optimal organization	
	OPM - Maintenance
	OPR - Reliability engineering
ORE - Own RED	
	ORS - Stand-alone
	ORI - Integrated
	ORN - None (reasons)
RFR - Reasons for RED	
	RFG - General
	RFO - Own
EIS - Expected improvements and savings	
ISQ - Improvements and savings quantified	
ACH - Achievement	
	ACN - None (reasons)
MEE - Measuring efficiency (KPI etc.)	
MEO - Measuring others	
PRR - Particular reasons for RED	
ADD - Additions	
QTP - Quotable text passages	

A total of 663 codes were assigned, indicating an average of 41 codes per document. The actual number per transcribed document varies between 21 codes as the lowest number and 66 codes as the highest number. It became apparent that the

code system developed was ideally suited for the present interview reports and did not need to be adapted further. This was also reflected in the fact that after coding the first group of ten transcripts, the number of codes did not need to be adjusted for each subsequent document. Initially, 35 codes and sub-codes existed, which were successively reduced to 26 codes and sub-codes during the analysis of the first documents. Once the tenth document had been coded, this number was not modified.

The next step was to analyze and interpret the data. Here, the respective answers were now considered thematically and summarized. The results of the analysis are presented in sub-chapter 5.4 - Detailed Findings.

In addition to the summarization, Mayring describes the primary forms of interpretation of the collected material. These relate to three different analytical techniques that should not be seen as sequential steps in a process:

The first approach, "Summary," involves condensing the material while retaining its essential content. This method distills the information into a manageable core that still captures the primary material's essence. It is about simplifying and abstracting the data to create a more digestible and coherent representation. The second form of interpretation, termed "Explication," probes into the finer details of the collected material. This approach focuses on specific text elements, such as terms or sentences, that raise questions or require further clarification. Additional material is introduced to clarify and expand upon these potentially ambiguous or complex passages to enhance comprehension. Explication thus acts as a means to provide context and depth to the material being analyzed. The third and final form of interpretation is "Structuring." This approach involves the application of predefined criteria or orders to the material. It filters out certain aspects or elements from the data, creating a cross-section aligning with these criteria. Alternatively, the material may be assessed against specific criteria, allowing for a systematic evaluation of its content. Structuring aids in organizing and categorizing the collected material, making it more manageable for subsequent analysis (Mayring, 2015). The summarization process was considered the best scientific method for the present work due to the enormous amount of data.

The last phase involves the creation of a report and documentation. Data reporting is also performed in the next sub-chapter, after which the data is archived.

There were no missing general values (non-response) in the interviews conducted. All participants answered the questions asked according to their own understanding. There was neither a complete refusal on the part of the intended participants (unit non-response) nor were any questions identified for which no information was provided (item non-response). There were a few unintelligible words in the transcriptions of the interviews, but these were explicitly marked. Nevertheless, they did not affect the quality of the answers. The meaning was retained in each case, and no question remained unanswered, incomplete, or distorted.

5.4 DETAILED FINDINGS

A total of 16 participants participated in the qualitative expert survey. The interview guide contained 14 main questions and six in-depth questions. To better organize the interviews, they were divided into six thematic sections and presented to the participants. The results are presented in the order of these sections.

These include:

- basics/organization (questions a–e)
- reasons why companies want to implement a reliability engineering department (questions f–k)
- expected savings through the implementation of a reliability engineering department (questions l–o)
- evaluating the effectiveness of a reliability engineering department (questions p–r)
- achievable savings through a separate reliability engineering department compared to a conventional setup (question s)
- concluding remarks (question t)

Please refer to Subsection 5.3.4 - Identifying Questions for the Main Study for an explanation of how the questions were identified and how the questions were grouped into different sections.

5.4.1 Section 1 – Basics/Organization

Question a: In which position do you work?

In preparation for the participants' planning, the aim was to interview specialized experts from general maintenance, reliability engineering, and production. The responses show this was entirely successful. All participants currently work in the mentioned areas. These participants include a variety of professionals involved in reliability and maintenance engineering aspects. They include reliability engineers, reliability managers, an area engineer who manages a specific production area from a maintenance perspective, a director responsible for maintenance and engineering, an engineering manager, and other maintenance and production managers. For a better overview, please refer to the illustration in Figure 40.

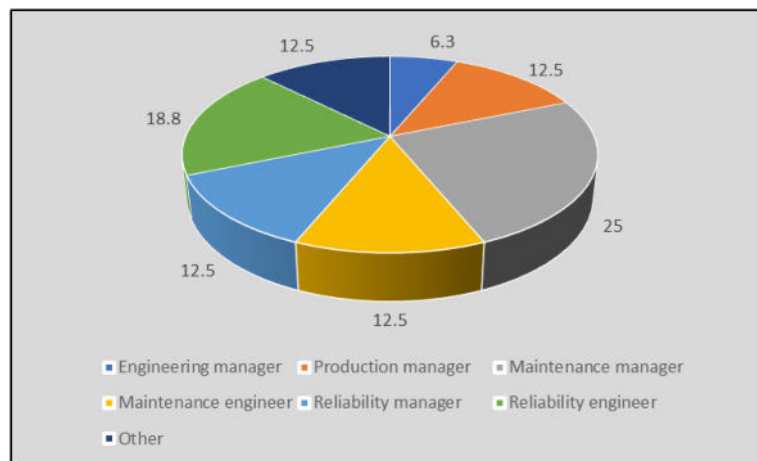


Figure 40: Participating professions [%]

It can be rightly assumed that this field of participants is suitable for answering the questions satisfactorily.

Question b: If relevant: In which positions were you previously employed?

This question was used to determine whether the participants in the study also had information from related subject areas. Here, the picture was more diverse. While one participant stated that this was his first position after graduation, another stated that he had previously held six other positions in the technical field. All participants, except the university graduate, had previously worked in related technical fields. Sometimes, in a different company in the same position. Four of

them had previously worked in the project area. However, some experts have worked as external consultants for reliability issues, as continuous improvement managers, in product development, or as process technologists. In more detail, participants have previously held positions in engineering, service, and reliability management. These included reliability engineers, local and global managers, and plant and area engineers. There were also area maintenance, engineering, and maintenance managers, global technical managers, and technical managers. Some participants had titles related to project management and design, such as project engineers, project managers, and service and reliability experts. Others were previously in the areas of continuous improvement, change consulting, and process technology.

Therefore, it can be inferred that the participants, as a group, possess supplementary and broadened expertise from related professional domains..

Question c: How long have you been concerned with the topic of "reliability engineering" and in what context?

The time frame of the participant's relationship to the topic of reliability engineering is also quite different, varying between three and 25 years, with an average of 13.4 years. The distribution across participants is summarized shown in Figure 41. Some respondents state that they only came into contact with the topic of reliability in their current position, while a larger proportion indicates that they were already in contact with reliability engineering in their previous position(s).

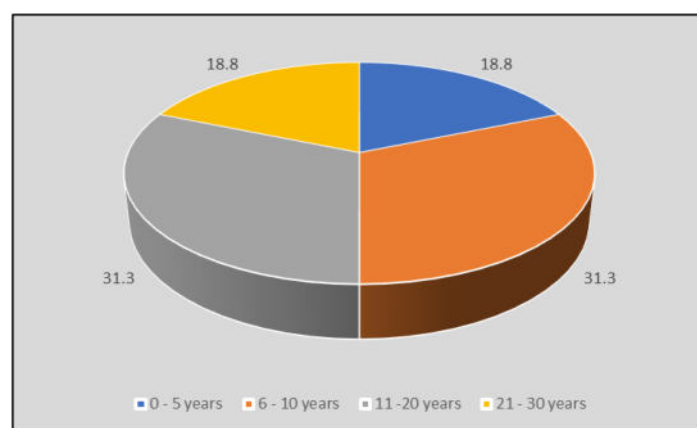


Figure 41: Concern with reliability engineering [%]

On the one hand, this shows that they are experienced experts in this area, but also that in the technical area of an industrial company, many positions relate to reliability engineering.

Question d: How is your maintenance organization structured and how is reliability engineering integrated there?

The answers to this question reveal a thoroughly different picture. Many companies have a central maintenance department. This department serves the production facilities connected to the site. One participant stated that the maintenance department at the site had to look after all five production plants located there. However, in several companies, there is also an organization that concentrates on the respective asset areas. Each area (called a plant) at the site has its own maintenance structure with engineers and craftsmen. It is noticeable that the division into mechanical, electrical, and, if necessary, measurement and control technology still exists at many locations. Several participants also state that there is a distinction between day-to-day maintenance, standby maintenance, and departments with a long-term focus, such as reliability or project engineering. Also, companies may keep specialists or even specialized workshops such as those for pumping, lubrication, general coating, lead coating, or infrastructure. Shift teams, composed of mechanical and electrical specialists, take care of day-to-day operations, breakdowns, and reliability. The day shift handles more complicated issues. Some shift teams may focus primarily on reactive work and problem-solving. There is reporting to an overall maintenance manager at several sites, but not everywhere. This manager, in turn, often reports to the site manager. At some sites, the maintenance manager is a member of the site leadership team. Some companies also have a central engineering department that oversees various projects and equipment. Maintenance planners and contractors are also part of the maintenance structure.

Regarding a RED, most participants stated that the RED, or a single reliability engineer, works centrally. Here, the department works in preventive maintenance or the analysis of plant data and is free from daily maintenance activities. Some reliability engineers focus only on pumps (or rotating equipment in general) or CAPEX projects in individual plants. Often, the RED is integrated into general maintenance, but it is sometimes independent. In some cases, reliability is treated as a cross-functional responsibility rather than centralized, with each plant

engineer overseeing reliability for his or her area. One participant indicated that a dashed line shows the relationship to maintenance on the organizational chart. However, it is also found in many plants that reliability is a component of the work of the respective asset managers or maintenance engineers.

Nevertheless, some businesses also work in the area of reliability in the field of craftsmanship. For example, temperature or current consumption measurements can be mentioned here. Three participants stated that reliability activities are carried out but that no separate RED exists. A consultant for reliability tasks in one company is available for all sites.

Reporting structures can also vary, with roles such as technical directors and plant managers overseeing these functions, sometimes with global or centralized support functions.

In the companies surveyed today, maintenance is still organized in a variety of ways. There are "classical" ways with centralized maintenance at the site, which is at least divided into mechanical and electrical, but there is also a decentralized allocation to the different asset areas. The organization of the RED also shows that it is often integrated into maintenance as an independent area. However, several companies have decided not to concentrate reliability tasks in one RED but to divide them among other employees.

Question e: If required for in-depth study: What should the maintenance organization look like from your point of view – especially with regard to the reliability engineering department?

It was stated several times that organizational improvements could be made at the respective location, but other participants stated that their current organization is excellent. Many answers for improvement refer to the fact that better cooperation is desired, especially between the production team and the general maintenance team, as well as between the production team and the RED. One participant stated that more employees are generally needed for the day-to-day business, whereas another participant stated that the maintenance employees should be firmly assigned to their areas in a matrix organization.

Concerning reliability, several participants said that they would like to have a responsible person for their respective areas. One person stated that he would

like to have centrally located reliability engineers as well as reliability engineers for each operating area. It is clear from the responses that the majority would like to see a RED that is independent of other maintenance work. One participant can also imagine that the RED is active across all respective company sites. The focus here should be on life-cycle management and other long-term topics. Several times, it was emphasized that RED must see itself as a team with the other departments, even if it can act independently. Various activities were indicated that the RED should work on. It was often indicated that data collection and analysis should be done based on a CMMS (usually SAP is indicated here). Also, primarily, preventive or predictive work should be done. More specifically, vibration measurements, ultrasonic measurements, and magnetic measurements of welds are indicated here. Another participant stated that he would expect the RED to be involved from the design phase onward to make the machine more reliable.

The responses show that the experts surveyed expressed a desire for a stand-alone RED for their site that is strongly connected to all departments. Even if the focus on the tasks to be performed by a RED varies, it is clear that the employees of the RED must also concentrate exclusively on their work. The emphasis should be on analysis and prevention.

5.4.2 Section 2 – Reasons why Companies want to Implement a Reliability Engineering Department

Question f: Does your site/company already have a stand-alone reliability engineering department?

The answers to this question show a somewhat mixed picture. In some companies, a separate RED is partially embedded in maintenance but acts independently. Between one and four engineers work full-time in this department. Two participants stated that the RED is an independent, cross-site department with one engineer each. At other sites, reliability activities are not located in a stand-alone RED. Instead, reliability was stated several times as a part of in-house maintenance activities. These activities refer primarily to preventive maintenance tasks. It was repeatedly indicated that the department is not called reliability engineering in the respective company but carries out the activities assigned to such a department. One participant stated that a selected person in his company plans reliability tasks,

but his department is not named RED. The information is supported by concrete activities carried out by the respective companies. For example, the electricians in some companies carry out inspections and calibrations of electrical equipment. One participant said that this is more complicated on the mechanical side. For example, the specialists might inspect pressure vessels or check rotating equipment. They also work to prevent errors from occurring in the first place. Two participants reported that they did not have a RED. For a better understanding, the answers to this question of the expert survey have been summarized in Figure 42.

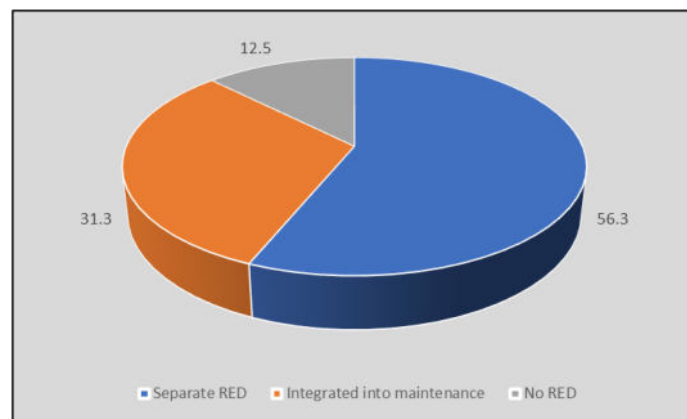


Figure 42: Reliability engineering types [%]

The answers reveal many possible ways to implement reliability activities in a company. Whether these activities are integrated into general maintenance or, instead, the company opts for a separate RED, as is the case with most of the participants surveyed, certainly depends on many influences, such as the size of the company and the type of production.

Question g: If no: Do you intend to introduce such a department soon?

The two participants who do not have a RED indicated that it would not be implemented at their sites in the near future.

Question h: If no: Why not?

Both participants have had a RED at their respective sites in the past, which has been eliminated. In one company, the maintenance staff was reduced to such an extent that there was no longer any staff available for reliability activities. Here, this is not expected to be re-established in the foreseeable future. A comprehensive

reorganization occurred in the other company, and the RED was dissolved. The engineers from the RED are now performing other tasks. General maintenance has taken over a few of the reliability activities in this plant. Again, it is not expected that a RED will be re-established as a separate department any time soon. Both participants would like to see a RED reintroduced at their companies to varying degrees.

It turns out that the vast majority of companies carry out planned reliability activities. However, in the few companies where this is not the case, the experts surveyed would like to see this happen.

Question i: Why do you think more and more companies are introducing a stand-alone reliability engineering department?

The responses to this question overwhelmingly indicate that the survey participants believe the reason is mainly the costs at the site. Participant #1 said, *"if a company sees that an own reliability department is very effective to reduce maintenance costs and production losses. So they implement their own department for this context."* These costs can be direct maintenance costs, the prevention of production losses, or life cycle extensions, which lead to the long-term sustainability of a company's assets. Nevertheless, it is also noted that there are improvements in EHS or quality due to a RED. These departments can implement safety measures and practices that mitigate several risks. One participant states that the reason for a RED is to have the machines available when they are needed. It has also been mentioned multiple times that it is important to have the newest technology available, implement optimal strategies, and better analyze the existing equipment. Companies are trying to use innovative approaches, tools, and methods to optimize their maintenance practices and improve the reliability of their assets. These include advanced condition monitoring techniques, predictive maintenance, and data-driven insights that can lead to better decision-making. Two participants suggest that this is about standardizing activities. It was stated frequently that the reason for a separate RED was to allow the employees of this department to work independently from the daily business. This setup enables them to focus on long-term problems and work proactively.

In addition, the support provided by a RED is not limited to maintenance but extends to other departments within the company. By aligning their efforts with

other departments and sharing their insights, REDs can help improve processes and promote synergies throughout the company.

One respondent believes that the achievements of a RED can be better measured as a separate department. It was also pointed out that the people in a RED are needed for communication inside the business for consulting and driving cultural change.

The detailed responses are shown in Figure 43 for better understanding and clarity.

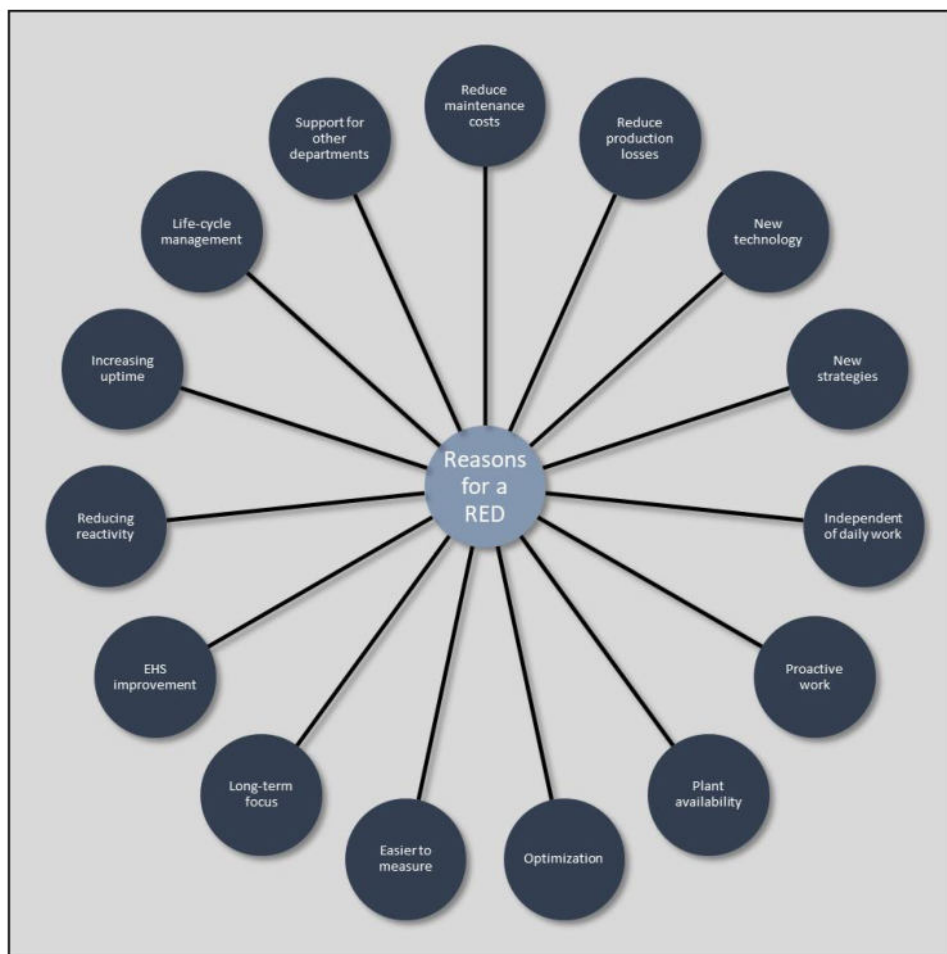


Figure 43: Reasons for a RED

The focus of the responses makes it clear that nearly all participants assume that a RED should first reduce costs. However, improvements in other areas are also mentioned. Most of the experts emphasized that employees in the area of

reliability would only have the necessary freedom to concentrate on these activities in a separate RED.

Question j: If yes to questions f or g: Are these also the reasons why you already have or intend to introduce such a department?

The responses to this question revealed that the answers given to the previous question were also the main reasons for the presence of a RED at that particular site. An exception as a note to the motivation for establishing a RED is, in addition to creating tangible business benefits in the form of cost reductions, but also in the form of shareholder satisfaction.

Question k: Are these the only reasons, or are there any others?

However, other reasons were noted in addition. For example, one participant reported that his site had successfully established a RED. Participant #7 stated that a RED means "less pain" for maintenance. It was also stated that some expertise is required at the site. Another reason given is the need to standardize and improve the maintenance strategy. Optimization of maintenance work based on CMMS data is also claimed. It was explained by participant #10 that *"The skillset of a reliability person is sometimes different than the one of a maintenance person, and also the mindset."*

It can be seen from the responses that the launch of a RED is not solely due to cost considerations. Rather, it is very diversified, which is vital to the experts surveyed.

5.4.3 Section 3 – Expected Savings through the Implementation of a Reliability Engineering Department

Question l: What types of improvements and savings do you expect from implementing a reliability engineering department

A large number of participants indicated savings in maintenance costs, reduction in production losses, and also reduction in variable costs (Fig. 44).

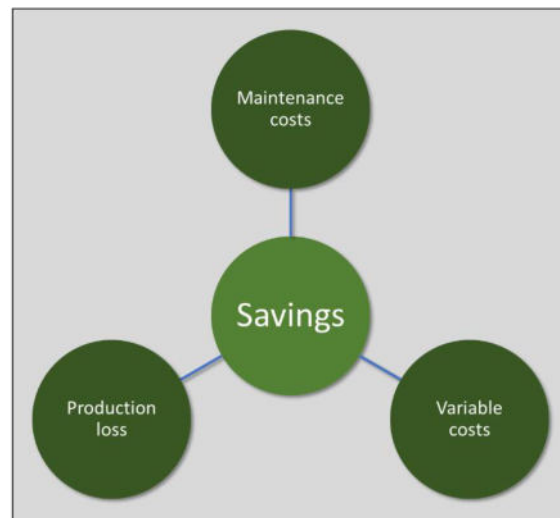


Figure 44: Expected savings

In the case of improvements, the field is much broader. In particular, it was stated several times that an improvement in production time and, thus, a reduction of downtime are expected. In addition, many responses were given only once or twice. Participant #7 said, *"The whole point of reliability engineering is making the asset last longer."* The survey participants presented a comprehensive package of improvements in various operations and maintenance areas, which should lead to higher overall performance and productivity. These improvements relate to maintenance strategy, occupational health and safety, product quality, and several other key areas. A well-thought-out maintenance strategy contributes to higher operational performance. It includes regular condition monitoring, which reduces the need for unplanned shutdowns and reduces the number of unexpected repairs. A proactive approach to maintenance and timely availability of spare parts results in fewer interruptions and downtime, leading to higher production volumes. Identifying and fixing bad actors and the components or equipment that cause the most problems was also addressed. It has a critical role in improving overall plant performance. This, in turn, contributes to higher Mean Time Between Failures (MTBF) and longer uptime. The Overall Equipment Effectiveness (OEE) has vastly improved through fewer shutdowns and efficient process engineering. Also addressed was the importance of technological advances, which are critical to achieving improvements.

For a better overview, the improvements mentioned by the participants have been summarized in Figure 45.

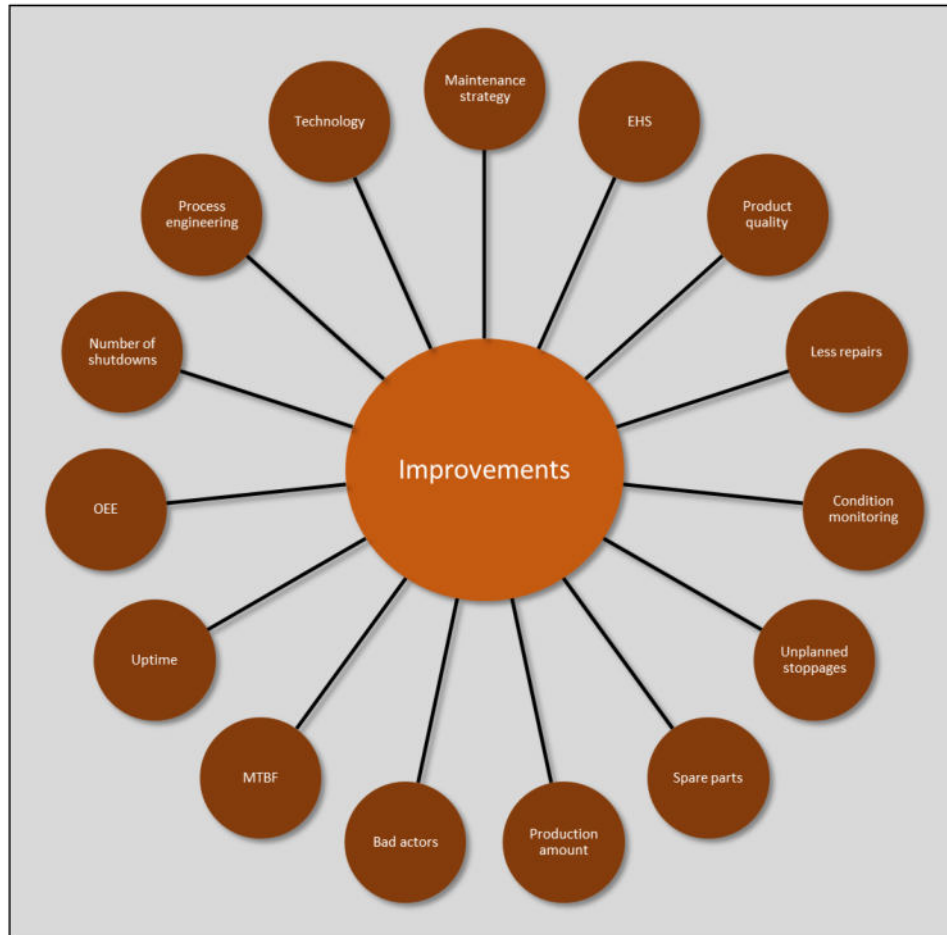


Figure 45: Expected improvements

A high expectation is evident here regarding the savings and improvements a RED can or must achieve. The focus on direct financial savings is clear from the answers given. It is also evident from the further expected improvements that these should substantively contribute to improving the company's short-, medium-, or long-term profit.

Question m: Can you quantify these expected improvements and savings (e.g., as a percentage to the maintenance budget or in actual totals)?

Most experts state that two to five percent savings are expected for maintenance costs. One participant said that a saving of up to 15 percent should be

possible in the maintenance budget. Another participant stated that the expected savings should compensate for inflation by two to three percent per year. This would amount to between US\$300,000 and US\$400,000 per year for the sourced company. Some data on production loss savings was also provided. A participant explained that savings in production losses of approximately 7,000t were expected, corresponding to a financial improvement of 21 million euros. Another participant even indicated the expectation of an improvement between 20 and 30%. In comparison, another participant reported that even an improvement of two or three percent is a considerable improvement. In the case of plant availability, the answers reflect the participants' quite different ideas. The figures range from 5 to 10%, 10 to 20%, or 10 to 15% improvement in plant availability. Another participant said a 3%, 5%, or even 10% improvement would be possible.

It was also said that a plant availability of 90% to 95%, depending on the plant area, is expected. Another statement concerned the execution of preventive maintenance. Here, a weekly fulfillment rate of 80% to 90% was expected. Another expert specified that the realization of all blue chip projects is expected. Finally, one expert pointed out that a one percent improvement in OEE would result in a financial improvement of £70,000 (see Figure 46 for a condensed graphical representation).

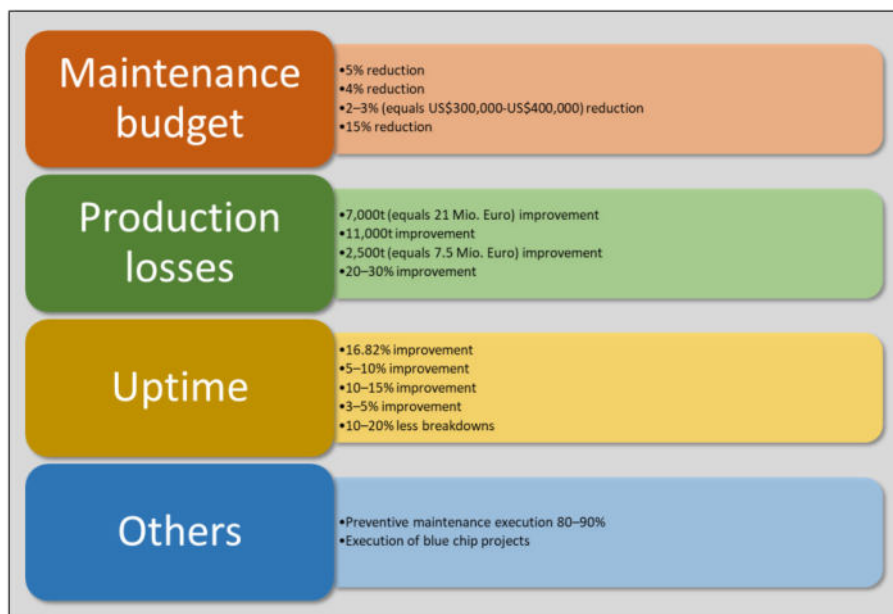


Figure 46: Quantified expected improvements through a RED

The respective companies' expectations of a RED are, for the most part, very ambitious. Regardless of whether direct costs are saved, plant availability is considered, or the fulfillment rate of preventive maintenance measures. In most companies, there are clear, measurable expectations about how a RED should contribute to business improvement.

Question n: Have these improvements/savings been achieved in the past?

The majority of participants indicated that they successfully achieved their expected goals. However, it is important to note that two individuals reported improvements without specifying the extent of those improvements. One mentioned that work is underway to articulate better and quantify the improvements, indicating a need for more precise metrics and measurement methods. In contrast, four cases were reported where goals were either not fully met or not met at all. These cases provide valuable insight into some companies' challenges in implementing their improvement strategies. One company reported a lack of time to measure financial savings, highlighting the importance of devoting sufficient resources and attention to the measurement process. In another case, recurring errors were cited as a barrier to achieving goals, underscoring the importance of addressing underlying operational issues. In addition, one case indicated that improvement actions had not been fully implemented, emphasizing the importance of a comprehensive and systematic approach to change.

It becomes clear that it is possible for most companies to achieve even ambitious goals through well-executed actions. However, it also shows the need to clearly define how results will be measured and to set a specific timeframe for implementation.

Question o: If no: Can you say why not and in what time frame do you think the savings will be achieved?

No substantive responses were made to this question.

5.4.4 Section 4 – Evaluating the Effectiveness of a Reliability Engineering Department

Question p: How do you track the efficiency of the reliability engineering department?

The experts responded that they use a number of different key performance indicators to evaluate their maintenance and reliability activities. These KPIs cover various aspects of operations, such as maintenance costs, production losses, and equipment reliability. Participants emphasized the importance of tracking maintenance costs, including cost savings and loss accounting. The loss statement helps evaluate product losses due to maintenance and equipment failures, while the cumulative loss statement enables the evaluation of year-end improvements.

In contrast, a few participants do not currently use KPIs, often due to a lack of SAP integration. However, most companies stress the importance of tracking various KPIs to optimize service and reliability practices.

Question q: Which key performance indicators (KPIs) do you use?

Maintenance costs were considered an important factor here. In the case of the specific KPIs, MTTR and MTBF are mentioned in particular, but the participants also refer to them as downtime or breakdowns. The KPIs are generally based on data from the CMMS. The number and costs of work orders are mentioned here, as are the bad actor analyses. Several participants stated that they generate many KPIs from the CMMS without going into detail. Other KPIs, some of which were only stated by one person, were how many RCAs were performed in a specific time unit or the efficiency of the craftsmen. Nevertheless, production indicators, such as production costs per ton of product produced or the production volume, are also considered. One participant stated that EHS indicators are also used. Two experts said they do not currently use KPIs or do not have CMMS data available. The KPIs predominantly used are summarized in Figure 47.

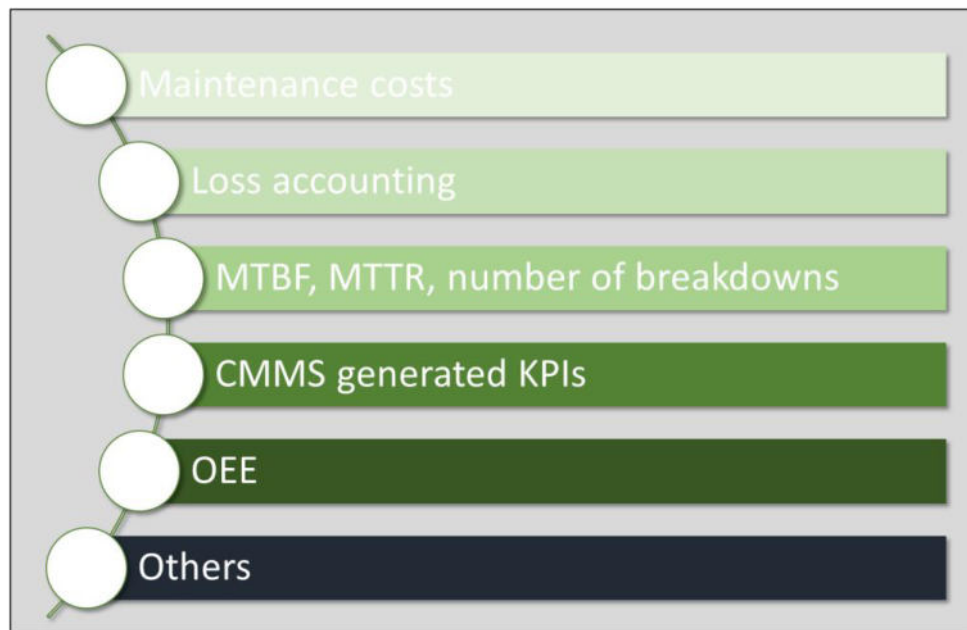


Figure 47: Used KPIs

In most companies, there are guidelines as to which KPIs are considered. However, these vary widely from company to company. Even if the data is determined from a CMMS, there are countless possibilities. No KPIs were determined for the surveyed companies that do not use a CMMS.

Question r: Are there any other aspects that you use to see or measure effectiveness? Please elaborate if this is applicable.

Here, too, the interviewees made a large number of different statements. For example, one key figure is "the acceptance of the RED within the site." Others were monitored at the corporate level but not specified. It was also stated that evaluating maintenance budgets and the replacement value of assets is controlled, targeting a range of three to four percent of maintenance costs relative to the replacement value of assets. Production losses are closely monitored weekly and monthly in collaboration with the plant teams. The evaluation of OEE includes daily, weekly, and monthly counts of machine failures. One participant states the focus is on the three machines with the most frequent breakdowns. Others report that their focus is not only on production losses but also on maintaining product quality.

In addition, standard procedures and measurement of the number of work orders are used as KPIs. Furthermore, compliance with regulatory inspections and

service of critical equipment, timely completion of work orders, and proper use of systems are monitored. A "breakdown tracker" is used in one company to track incidents. Similarly, another company monitors the number of root cause analysis investigations. Also, material costs are monitored in one company.

Some participants also indicated that they did not perform any further measurements.

It was demonstrated that multiple approaches exist for determining a RED's effectiveness based on the company in question. Nevertheless, key figures that a CMMS can generate predominate. Soft factors are only used in rare cases.

5.4.5 Section 5 – Achievable Savings through a separate Reliability Engineering Department compared to a Conventional Setup

Question s: Taking all costs into account, what do you think are the particular advantages of a stand-alone reliability engineering department?

There were quite different answers to this question. However, a clear focus emerged, which most participants addressed: that the resources for reliability are not consumed by day-to-day business. Participant #7 stated, *"It's not a pleasurable experience to have your day and your week destroyed by how the plants' performing."* Likewise, participant #10 responded, *"The advantage is to me that, first of all, a project can be driven because the resources are not eaten up by other departments."* Several times, it was noted that this was the only way to ensure that the respective engineers could focus on long-term and preventive measures. Participant #16 describes this as *"you do have people who think ahead and you don't have the time and you're running production."* Likewise, it is stated that reliability issues should already be anticipated, as should the spotlight on the latest technologies. Participant #9 said that the RED is there "to think out of the box." It is also often mentioned that the most important advantage of a separate RED is that it increases plant availability and thus reduces plant downtime. However, it was also crucial to the experts interviewed that a RED improves machine condition monitoring and that more data be available. Another answer referred to the fact that spare parts are better organized. Other individual opinions referred to obsolescence management or the development of inspection routes. Saving life cycle or maintenance costs were also mentioned. It was also noted that with a RED, the production process would be more stable.

Once more, it was stated here that the employees of a RED could only freely pursue their work if they were independent of the daily work to develop new ideas and introduce current technology.

5.4.6 Section 6 – Concluding Remarks

Question t: Would you like to add to or elaborate on any of the questions?

Again, it was said that the daily business must not deplete the RED. Also, reliability work is a collaboration; sharing information and documenting the achieved savings are essential. Referring to this, Participant #7 said, *"I think reliability is very much a partnership."* It was also stated several times that working more proactively and less reactively is essential. It was stated that there is always a need to develop new ideas to enhance the work. One participant said that the focus of the RED must not only be on mechanical improvements but also on improvements in E&I and DCS. Participant #9 stated, *"I think that reliability engineering, reliability-centered maintenance is a huge topic that will be confronted in so many departments of so many companies."* Participant #12 said, *"I think it is very good to have, I think, for all our plants, to have a reliability department. With people very involved in the knowledge of the plant and the maintenance and production part."* Participant #7 said, *"My biggest problem with reliability engineering is our site is run by process engineers."* An expert said that he believes his plant does not have many unplanned failures, so it can be said that they have good reliability engineering. Other comments stated that a RED is the future. Finally, one participant said he would like a guideline on what to achieve with a RED and how to start one.

The concluding remarks made it apparent that many previous statements were reaffirmed. In general, the experts surveyed were very positive about a separate RED and considered it indispensable for a company's future.

5.5 RESEARCH QUESTION AND SUB-QUESTION FINDINGS

This section summarizes the main findings of the analysis and considers them in relation to the sub-questions and the research question. Numerical values are predominantly extracted from the preliminary study.

Sub-question 1

"What are the anticipated outcomes or benefits that companies or certain facilities aim to achieve when establishing a reliability engineering department?"

The answers to this sub-question provide a revealing insight into the primary objectives of the companies studied. The main focus is on cost reduction. Three priority areas have been identified that are attracting a high level of attention: reducing production losses, increasing uptime, and reducing maintenance costs. These are the core areas where companies seek to optimize their operations and financial efficiency.

However, it is worth noting that cost-reduction efforts extend beyond these critical areas. Spare parts costs are also among the additional expenses that companies are actively seeking to contain. This illustrates a multi-layered approach to financial optimization and shows that companies look at different aspects of their operations to achieve cost savings.

Beyond the direct financial benefits, companies expect several other improvements from establishing a dedicated reliability engineering department. In particular, they expect distinct improvements in environment, health and safety (EHS), and quality management. These expectations indicate a broader commitment to overall operational excellence and compliance. In addition, companies anticipate the development of internal technical expertise that will provide critical support and guidance to production and maintenance personnel as well as senior management. This internal expertise is expected to equip employees with the knowledge and tools they need to make informed decisions and drive continuous improvement.

A fundamental expectation is the adoption of data-driven decision-making processes. The collection and analysis of machine data and the production of relevant statistics are seen as critical to achieving operational quality and cost reduction. This underscores the increasing importance of data-driven strategies in modern business environments. There is also a focus on ensuring access to the latest technologies in the workplace. The pursuit of standardization is also an essential theme, suggesting that companies want to streamline processes and achieve consistency in their work. One particularly notable aspect that emerges from the

survey results is the desire for a separate RED so that departmental employees can work independently of day-to-day operations. This recurring statement underscores the importance of creating a separate unit that can focus on long-term strategies and goals without being impacted by the immediate demands of day-to-day operations.

In summary, the responses to this sub-question draw a wide variety of motivations and expectations that have led to the introduction of a separate RED in these organizations. It is clear that cost reduction is a primary concern, but this drive is accompanied by a broader commitment to improving various aspects of operations, advancing internal expertise, introducing data-driven decision-making, and enabling long-term strategic planning.

Sub-question 2

"What are the expectations and performance indicators that companies associated with the contributions of a reliability engineering department in terms of cost savings, minimized production losses, and increased equipment uptime?"

The companies considered in this study that operate a RED have different expectations and performance indicators when it comes to evaluating the contribution of this department. In most participating companies, the performance indicators of cost savings, minimized production losses, and increased equipment uptime are addressed, albeit with varying degrees of intensity.

An important consideration in evaluating the department's performance is the cost savings it should achieve. Expected reductions in maintenance costs can vary widely, with some companies expecting no savings while others expect savings of up to 30%. On average, savings of about 7.9% are expected across all results. The expert interviews generally confirmed these results, although the actual values were somewhat lower than expected on average. Another critical performance indicator is the reduction in production losses. On average, companies expect to reduce production losses by 8.8%, with expectations ranging from 0% to 30%, depending on the company. The expert interviews also confirm these expectations, with some companies aiming to reduce product losses drastically. For example, it was stated that a reduction of 2,500 and 11,000 tons should be achieved, translating

into considerable financial gains ranging from 7.5 million to 21 million euros. The uptime of the plants, i.e., the extension of the operating time of the plants, is also an important performance indicator. Here, it is evident that expectations in this area varied greatly from company to company: Some expect no improvement, while others aim to increase uptime by up to 99%. On average, the expectation for improvement is 8.7%. The experts' expectations tend to be slightly higher than the preliminary study results, with some experts expecting a 10% to 20% improvement in unplanned machine downtime, resulting in better equipment uptime.

In addition to these quantified expectations, some companies have additional requirements, such as performing 80% to 90% preventive maintenance, maintaining equipment availability at 90% to 95%, and successfully completing all blue chip projects. These specific goals show that companies have clear and measurable expectations for how their REDs should contribute to profit improvement.

In summary, expectations and performance indicators for companies operating a RED include savings in maintenance costs, reduction in lost production, increased equipment uptime, and several other specific goals. These expectations vary from company to company and are supported by the preliminary study and expert opinions emphasizing the importance of reliability engineering in improving overall operational efficiency and profitability.

Sub-question 3

"What methods and criteria do companies or facilities employ to assess the effectiveness and impact of their reliability engineering department?"

Organizations use various methods and criteria to evaluate the effectiveness and impact of their reliability engineering department. The primary approach commonly used is the use of key performance indicators. These KPIs are typically generated by a Computerized Maintenance Management System (CMMS), with many organizations relying on the SAP system to collect, monitor, and evaluate these metrics. The range of KPIs used varies, with some companies tracking only a single KPI, while most monitor multiple KPIs that are automatically generated regularly. The KPIs most commonly used to evaluate the effectiveness of the RED include maintenance costs, production losses, and plant uptime. Although participants use different terms for these KPIs, such as equipment availability, uptime, Mean Time Between Failures (MTBF), or the number of machine failures, the essence of

evaluating reliability remains the same. In addition, some companies include other KPIs such as Overall Equipment Effectiveness (OEE), Environmental, Health, and Safety (EHS) metrics, Root Cause Analyses (RCAs) performed within a given time period, craftsman effectiveness, production cost per ton produced, production volume, and various other numbers generated by the CMMS. It should be noted, however, that some participants may not be aware of all the KPIs used, and in rare cases, some companies do not use KPIs at all to evaluate their RED.

Furthermore, to KPIs, participants also mentioned alternative methods for measuring the effectiveness of a RED. These include tracking the replacement value of assets, assessing effectiveness at the company level, monitoring the completion of regulatory inspections, assessing the number and duration of unplanned shutdowns, and considering the cost of materials. One qualitative aspect that was mentioned is the acceptance of the RED at the site as an indicator of its effectiveness. This underscores the importance of not only quantitative data but also the perception and satisfaction of this department within the organization.

Moreover, the qualitative survey provided a deeper perspective and revealed that participants without a local CMMS tend not to use KPIs. It also revealed that some experts were unaware of the available KPIs, which could explain why they were not used in certain cases. Overall, these findings underscore the variety of methods and criteria that organizations and facilities use to measure the effectiveness and impact of their reliability engineering department, which go beyond traditional CMMS-generated KPIs to include both quantitative and qualitative indicators of success.

Sub-question 4

"What organizational strategies and practices are employed to integrate a standalone reliability engineering department into the overall company structure?"

Integrating a stand-alone reliability engineering department into the overall corporate structure can be a complex but essential process. The study offered insights into the participating companies' different organizational strategies and practices in this context. Initially, it is worth noting that most companies have a relatively small RED team, typically consisting of fewer than five employees. The

interviews revealed that the position of the RED within the organization can vary widely. While the majority of participants indicated that the RED typically resides within the maintenance organization, there are other organizational affiliations. In some organizations, the RED reports directly to various departments, such as the site manager, the research and development department, or general engineering. In some cases, reliability engineering activities are not grouped in a separate department but are integrated into the responsibilities of asset managers or maintenance engineers, making them part of the maintenance function. In addition, at some manufacturing facilities, the RED has a broader role, overseeing and supporting multiple assets simultaneously.

The study shows that not all employees in the reliability engineering department work exclusively in this area. Nevertheless, more than two-thirds (70.8%) of these employees work exclusively in RED, while less than one-third (29.2%) are involved in other activities and employed in other company areas. This variability of roles within the RED underscores the flexibility required to integrate the department effectively.

In addition, the specific activities performed by a RED may vary from company to company. For example, in 41.7% of companies, hydrocarbon management is one of the responsibilities of a RED. However, in other companies, these activities are managed by separate departments. This variability highlights the need for alignment and customization to meet the specific needs and goals of the company. Reporting lines within the organizational structure also reflect this diversity. The majority of REDs generally report directly to the maintenance manager, indicating close alignment with maintenance functions. However, approximately 41.7% of sites have a different reporting structure, with some REDs reporting directly to the site manager, engineering manager, or even the general manager. This diversity of reporting lines suggests that the structure should be tailored to the unique culture and needs of the organization.

In summary, integrating a standalone RED into the overall structure of the company requires an approach that is appropriate for the particular company. Specific policies and practices may vary depending on the size of the department, the nature of the industry, and the specific needs and goals of the organization. It is essential to carefully consider reporting lines, departmental responsibilities, and alignment with other functional areas to ensure seamless integration.

Sub-question 5

"What factors and considerations, beyond immediate cost analysis, influence the perceived impact of establishing a separate reliability engineering department on a company's profitability?"

Beyond the immediate cost analysis, there are numerous factors and considerations that have a noteworthy impact on how establishing a dedicated reliability engineering department affects a company's profitability. First and foremost, the ability of a dedicated RED to pool its resources is a crucial advantage. By specializing exclusively in reliability, these teams can work with a strong focus and ensure they are not distracted by other operational activities or daily tasks. This undivided attention can be critical to improving reliability. Likewise, more informed and strategic decisions can be made due to this greater independence.

In addition, having a separate reliability department allows for a more comprehensive assessment of lifecycle costs when projects are initiated. Rather than simply going for the cheapest equipment, these teams can take a long-term perspective. A forward-looking approach is another benefit. Dedicated reliability teams are better able to anticipate and address potential problems proactively. Specialized expertise in a RED is also a valuable advantage. Reliability engineers in a dedicated department can develop specialized knowledge and skills, ensuring they have the expertise to focus on reliability improvements without dealing with unrelated tasks.

Furthermore, a dedicated reliability department can focus on technology and stay on top of the latest advances in condition-based maintenance strategies. They can look at technologies such as vibration, acoustic, and condition monitoring, which can lead to improved predictive maintenance and higher reliability. Similarly, a dedicated RED helps improve production. Focusing on reliability can increase equipment availability, reduce downtime, and extend the time between maintenance interventions, ultimately increasing the stability of the production process. Cost reduction is another compelling aspect. A dedicated reliability department can contribute to cost savings in several maintenance areas by optimizing spare parts, reducing obsolescence, and implementing more efficient maintenance practices. The RED can also be responsible for performing regular inspections and

preventive maintenance. They can establish inspection routes and monitor critical components' condition, extending their life and reducing maintenance costs. Monitoring the performance of production machinery is also an area where dedicated reliability teams excel. By focusing on reliability tasks, they can exercise better control and oversight, which can translate into improved overall efficiency. A RED can tailor its approach to the specific needs and size of the organization, ensuring that the reliability of the engineering investment is precisely tailored and cost-effective.

In conclusion, establishing a separate reliability engineering department goes beyond immediate cost considerations and can positively influence a company's profitability. It can improve equipment reliability, reduce maintenance costs, promote a forward-thinking, technology-driven approach, and provide a number of other benefits.

Research Question

"What are the key operational and organizational components for reliability engineering departments to improve a company's performance in the manufacturing industry?"

The operational and organizational components of reliability departments in manufacturing companies are diverse and highly adaptable to individual companies' varying characteristics and requirements. REDs play an important role in optimizing manufacturing processes' overall efficiency and cost-effectiveness. The organizational structure is closely intertwined with operational objectives to achieve success. It is vital to be aware of the great diversity in the manufacturing industry, which includes variations in product types, manufacturing processes, workforce size, and other critical factors. Nonetheless, there are certain common themes to the successful operation of a RED while also allowing for customization to meet a company's unique characteristics.

Operationally, a RED is primarily focused on reducing costs for the business. This goal is typically achieved through a proactive rather than a reactive approach. Many manufacturing companies rely on predictive or preventive maintenance strategies, often combining elements from both areas. Consequently, a RED is vital

in planning machine condition assessment and evaluation activities. An essential operational function of a RED is data collection and analysis, especially regarding machine performance. Various techniques are used for data collection, including vibration measurements, ultrasonic measurements, magnetic measurements of welds, temperature measurements, and other nondestructive methods. The data collected, including information from computerized maintenance management systems (CMMS), is carefully analyzed to provide actionable insights to maintenance and production personnel and management. In some cases, REDs also oversee hydrocarbon management tasks and perform in-depth analyses such as failure mode and effects analysis (FMEA) and root cause analysis (RCA).

Furthermore, REDs perform reliability engineering projects and develop repair and maintenance instructions. This also includes optimizing strategies and activities related to lean management and audits. Depending on the company structure, REDs may also be responsible for inspecting and calibrating electrical equipment. In addition, they actively work to standardize reliability measures and improve maintenance processes within the organization, ensuring that the latest technologies are available to improve reliability. Effective communication within the organization is also a core responsibility of RED staff to ensure that reliability-related information is shared seamlessly.

Regarding organizational components, the placement of the RED within the organization should harmonize with the overall organizational structure. The most common approach is to integrate the RED as a separate department within the maintenance department, but other organizational solutions are also feasible, considering factors such as company size and complexity. The head of the RED usually reports directly to a higher-level manager, who is often the maintenance manager but may also be the site manager or the general manager, depending on the company's specific needs and organizational hierarchy. Within the RED, employees may have a variety of responsibilities, such as overseeing entire plants, specific plant sections, or specializing in areas such as electrical or mechanical components or specific machines/systems. Some specialists may focus exclusively on the generation and analysis of CMMS data. The size and scope of a RED are adaptable and must be based on the location and operational tasks it manages. A higher-level department overseeing multiple sites can be established in larger organizations to

standardize reliability measures across sites. Organizations may also consider hybrid solutions in which a cross-site department works with local REDs. The cross-site department can provide expertise and support to individual plants, while local REDs maintain an organizational link to the local structure.

A clear organizational separation between general maintenance activities and RED responsibilities is essential to ensure success. This separation ensures that staff can focus on predictive and preventive work without getting caught up in day-to-day operations. In addition, REDs are often assigned an independent budget to implement facility improvement activities. This budget independence gives REDs the ability to implement cost-effective reliability improvements.

In summary, the operational and organizational aspects of reliability engineering departments in manufacturing companies are focused on optimizing efficiency and cost-effectiveness and aligning operations with the specific needs and goals of the business. This approach promotes proactive maintenance strategies, data analytics, and clear organizational separation to ensure the achievement of reliability engineering goals.

5.6 HYPOTHESES

The findings presented previously in this thesis provide the basis for formulating hypotheses as the final step of this work. In particular, the detailed results of the research question and its associated sub-questions are referred to.

Qualitative research methods generate dependable and meaningful results. However, within the interpretative paradigm, a strict methodology is applied in qualitative social research, which generally prohibits the formulation of generalized arguments. It is emphasized that the approach must always be tailored to the specific subject area in order to ensure adequate interpretation and analysis (Lamnek & Krell, 2016). Bortz and Döring argue that the selection of supposedly typical cases cannot sufficiently justify generalizability. Instead, they emphasize that additional quantitative statements are required (Bortz & Döring, 2006).

The 15 hypotheses presented below mark the conclusion of this doctoral thesis. It is recommended that these be explicitly tested and explained in future

research. The hypotheses refer to the respective statements of the sub-questions of the research question.

Concerning sub-question 1 (SQ1):

Hypothesis 1 (H1): Manufacturing companies expect cost reduction by introducing a reliability engineering department.

Hypothesis 2 (H2): Manufacturing companies expect the introduction of data-based decision-making processes through the introduction of a reliability engineering department.

Hypothesis 3 (H3): Manufacturing companies expect to build internal technical expertise by implementing a reliability engineering department.

Hypothesis 4 (H4): In manufacturing companies, the reliability engineering department works independently of daily tasks.

Concerning sub-question 2 (SQ2):

Hypothesis 5 (H5): Manufacturing companies use the performance indicators of cost savings, minimized production losses, and increased equipment uptime.

Hypothesis 6 (H6): Manufacturing companies use the performance indicator of the completed preventive maintenance percentage.

Concerning sub-question 3 (SQ3):

Hypothesis 7 (H7): Manufacturing companies use key performance indicators to assess the effectiveness and impact of their reliability engineering department.

Hypothesis 8 (H8): Manufacturing companies use computerized maintenance management systems to generate their key performance indicators.

Hypothesis 9 (H9): Manufacturing companies that do not use computerized maintenance management systems do not use key performance indicators.

Concerning sub-question 4 (SQ4):

Hypothesis 10 (H10): In manufacturing companies, the reliability engineering department is a part of the maintenance organization.

Hypothesis 11 (H11): In manufacturing companies, employees in a reliability engineering department do not work exclusively in this area.

Concerning sub-question 5 (SQ5):

Hypothesis 12 (H12): A reliability engineering department works proactively in manufacturing companies.

Hypothesis 13 (H13): Reliability engineering departments work with a long-term focus in manufacturing companies.

Hypothesis 14 (H14): In the reliability engineering departments of manufacturing companies, reliability engineering personnel have specialized knowledge and skills.

Hypothesis 15 (H15): Manufacturing companies achieve better overall efficiency through the use of a reliability engineering department.

6 DISCUSSIONS AND RESULTS

6.1 DISCUSSION

Many studies in the past have dealt with the subjects of business administration, maintenance, and even reliability engineering. However, these mostly have a different focus than this work and have not considered the questions posed here in the necessary depth.

Concerning this, Aven describes in his article that there is no universally accepted definition of reliability engineering (Aven, 2017). This can be confirmed. In the course of this work, it could be clarified, for the term "industrial reliability engineering," which activities are carried out and which organizational forms are frequently used. It was found that many companies have already implemented a RED, even though this is not specified in the known standards for maintenance organizations. The characteristics of how and in which organizational form the RED is integrated into a company vary wildly, depending on the respective framework conditions of the company. On the other hand, the focus of a RED in the respective companies is primarily on saving costs. The activities of the RED employees for this purpose also vary depending on the company's framework conditions but are primarily concerned with medium- and long-term improvements.

Liao, Chen, and Yang describe the tension between production planning and scheduling maintenance work at minimum cost (Liao et al., 2017). A RED can be included as part of the solution. It has been proven that using a RED can increase the uptime of machines and equipment. This improvement means that fewer maintenance interruptions have to be planned. Likewise, a RED usually focuses on reducing unplanned downtime, which, as mentioned at the beginning of the article, thwarts any planning.

In a similar context, the paper by Chen and Bao describes an increase in system reliability through cost-reliability analysis (Chen & Bao, 2013). In the beginning, they state that increasing reliability is one of the main tasks of any manager. For this, the selection of the components must be considered, and qualified professionals must perform the analysis. In this situation, a RED can become active depending on the task at hand. After all, improving reliability is a primary objective for a RED.

Kareem, Saeed, and Faraj state that reliable inspections and planned maintenance can prevent the occurrence of unplanned downtime and, thus, poor uptime. In addition, they specify in their article that the reputation, safety, and ability to operate economically have also improved (Kareem et al., 2019). The first statement can be confirmed. Thus, the participants in the surveys stated that it is vital to work preventively and predictively. Most companies already work this way, which results in higher equipment availability and upcoming cost savings. As a result, the number of breakdowns has been reduced. Also, the second statement could be confirmed. It is given that increased uptime increases profitability. Likewise, many study participants stated that an effective RED and, thus, excellent preventive or predictive maintenance also increase the overall safety level. Whether the company's reputation increases simultaneously can be assumed but was not assessed in the study.

Rosqvist, Laakso, and Reunanen describe an approach for improved maintenance planning. They state that knowledge of interpreting failure, maintenance, and technical and operational data is required to estimate the impact on failure and degradation processes in order to introduce their planning method (Rosqvist et al., 2009). This statement can be applied to all planning methods at this point. In order to carry out effective planning, it is inevitable that one understands the technical interrelationships and also has the necessary data. Thus, the authors' statement can be confirmed. The survey has impressively shown that it is essential to most participants that a RED acquires, evaluates, and interprets machine data. This data can then be used to work preventively or predictively.

Waeyenbergh and Pintelon define in their publication that an increasing number of companies are looking for a maintenance concept tailored to their needs, as maintenance represents a large part of the total costs. In particular, they refer to the increasing focus on availability, reliability, and safety. For this purpose, they offer a framework of different, widely known concepts described in the literature (Waeyenbergh & Pintelon, 2004). This research confirms that no universal maintenance concept fits every company, as it depends on many local factors. It can also be verified that many companies are thinking about their future maintenance organization. However, it can be seen that these may well be concepts that are not standardized and are not described in detail in the specific literature. Companies are often thinking much further ahead about newer approaches. Here, the

introduction of a separate RED, which has hardly any echo in the literature, is explicitly mentioned.

The authors Barberá, Crespo, Viveros, and Stegmaier state that maintenance goals should always be closely aligned with business plans, as they are mutually dependent. Maintenance and business goals should, therefore, be closely linked. They also state that maintenance management is an increasingly important competitive factor in the economy. Furthermore, they describe how scientific models and applications in practice differ from each other. This makes it difficult for industrial companies to adapt existing models to their particular business environments (Barberá et al., 2012). This research has shown that maintenance departments can operate very differently within the overall business context of each company. Naturally, the business context and the maintenance goals are interdependent. Maintenance, in general, is financially relevant in every company, which is expressed in the context of this study by the fact that all REDs have to implement savings measures, albeit to different degrees. Thus, the authors' statement can also be affirmed. Whether academic models for maintenance management deviate from practice was not the core of this evaluation. However, the evaluation of the related literature showed that a large number of the relevant studies are not based on empirical figures. This fact could well lead to a discrepancy.

Steinborn shows that maintenance is an important production factor. It increases the quality of products and processes. Maintenance makes a sizeable contribution to a company's added value through its plant knowledge. In his article, he particularly refers to large plants in the chemical and petrochemical industries (Steinborn, 2005). This thesis shows that REDs are predominantly found in companies of this size and in these industries. REDs are expected to increase process quality (uptime) through their work. In addition, some companies expect an increase in quality in general. Thus, Steinborn's statements can be confirmed. The fact that a RED has extensive knowledge of the plant in the respective companies can be confirmed by the fact that in many companies, advising specialists and managers is a part of the work. As already mentioned, a major part of the work of a RED is the continuous reduction of maintenance costs. This makes it possible to contribute to industrial value creation.

By Erbe, Iung, and Morel, the claim is made that the majority of equipment is maintained either reactively or blindly proactively, regardless of whether service

is actually required (Erbe et al., 2007). This statement can be refuted. On the contrary, the collected data show that most participating companies follow a preventive or predictive maintenance strategy. In addition, mixed forms are also used. Only a small number of companies still pursue a purely reactive maintenance strategy.

Madu's paper reports that senior leadership involvement and commitment are key to ensuring that adequate attention is paid to reliability and maintenance management. It is also noted that reliability is the key to organizational survival and that reliability and quality are closely linked. The survival of organizations is not possible if they do not focus on these aspects (Madu, 2005). The present work could confirm the first statement. This view seems to prevail in the interviewed companies, as there is only one reporting line to senior management. Thus, the RED always reports to senior managers such as the maintenance manager, the site manager, or the general manager. The second statement can also be confirmed, as a large number of companies have recognized that the reliability issue is vital for the company's business context, and many companies are working on improving reliability, often with independent departments. However, it is not clear from the data collected that this is the only way to ensure the organization's survival.

Vishnu and Regikumar explain in their article that the focus of plant maintenance is to achieve a minimum of failures. Furthermore, the plants should be kept in good operating condition at a low cost (Vishnu & Regikumar, 2016). This research work can support these statements. Failures lead to a reduction in uptime and production losses. The extension of the production time and the reduction of production losses are indicated as the main goals and KPIs. Thus, it can be concluded that a minimum downtime should be achieved. The data also show that the lowest possible costs for maintenance tasks should be claimed. Here, too, it was also stated that reducing maintenance costs is another one of the main tasks. These are, therefore, very often provided with a KPI.

In the summary of their paper, Salonen and Deleryd describe maintenance as often being a very reactive process. They also state that maintenance departments are often seen as a cost factor that is often discussed, and budgets are reduced (Salonen & Deleryd, 2011). The first assertion that maintenance is primarily reactive has already been refuted. On the contrary, preventive or predictive maintenance strategies are preferred. However, mixed forms are also used. The second

statement can be confirmed insofar as the constant lowering of maintenance costs is regarded as one of the main goals in many enterprises.

6.2 METHOD CRITICISM

Before beginning the scientific investigation, the question arose about which research methodology would be most suitable. Initially, consideration was given to using a mixed-methods approach. This approach combines qualitative and quantitative research methods to understand a research subject comprehensively. However, after careful consideration, it was decided not to use this method. The decision against the mixed methods approach was based on the realization that the research question and its sub-questions could best be realized through a qualitative study. A qualitative study provides the opportunity to explore complex phenomena in great detail.

It was also recognized that very few publications explicitly addressed the particular niche that was the subject of the study. Therefore, it was decided to precede the explorative qualitative study with a descriptive preliminary quantitative study to create a certain database. The quantitative preliminary study was intended to gather general information and data, even though it was difficult to gain deep insights into the participants' companies through this. However, the limitations of a quantitative survey were also seen. Therefore, the preliminary quantitative study was seen as a first step rather than the final data collection. Therefore, conducting a qualitative survey of experts was considered necessary after the preliminary study. This approach promised to provide more detailed and informed results, especially from experts who could share their experiences and insights.

After conducting the scientific interviews, it was confirmed that the chosen research method was the right one for this research question as the qualitative research approach proved appropriate to achieve the desired results.

However, there were lessons learned from the methodology used. For example, the preliminary quantitative study revealed that using a free-response question was problematic because responses were highly variable and required a substantial amount of comparison. Closed-ended questions would have been more appropriate in this case. In addition, participants should be given options to indicate that they cannot or do not want to answer specific questions.

When conducting the expert interviews, it became apparent that open-ended questions led to participants answering in their own words. While this provided in-depth insights, comparing responses was complex because participants used different terminology and phrasing. To alleviate this problem, it might be helpful to establish standardized technical terms and definitions in the preliminary interview.

Another problem was that some participants digressed while answering the questions. To increase the comparability of the interviews, it might be purposeful to ask participants in the preliminary interview to answer the specific question first before providing further explanation. This should improve the structure and comparability of the interviews.

6.3 IMPLICATIONS

The study's findings indicate that establishing a dedicated RED can enhance corporate profitability in the assessed companies. These improvements may arise from direct cost savings, such as reduced maintenance expenses, or indirectly through minimized downtime, leading to increased effective uptime and lower production losses. These insights are particularly significant for senior executives, as they have the ability to implement an RED within their organizations. Cost advantages over competitors provide a crucial competitive edge.

Additionally, participants highlighted that a RED could contribute to improvements in the field of EHS. Ensuring workplace safety is a top corporate priority for all manufacturing companies today. Moreover, a company's ability to produce and deliver reliably through the support of a RED enhances its external reputation. This is beneficial not only for senior management but also for sales teams promoting the company's products.

This thesis underscores key aspects that can offer substantial advantages to businesses. It is up to senior managers in each organization to assess these factors and make informed decisions accordingly.

6.4 RECOMMENDATIONS

The study's findings demonstrate that the work of a RED can increase the profits of a manufacturing company in the companies surveyed. Thus, it can be recommended that all manufacturing companies examine in detail whether a RED can be introduced in their respective areas to achieve advantages. Companies that have already established a RED should check how it is integrated into the existing organization. This study demonstrates that the most common and optimal way is to let the RED operate independently. This is achievable with or without integration into the general maintenance department. Only in this manner can it be ensured that RED personnel are not bogged down in day-to-day operations but can instead focus on predictive and preventive measures for medium- and long-term issues.

Likewise, companies should verify which activities the RED is currently responsible for. It must be determined which activities promise the most effective improvements for the company. The focus of the RED should be reviewed at regular intervals and adjusted if necessary.

In order to prove how effectively a RED is working, it is essential to define and monitor specific key figures for the RED. These must correlate with the respective company's environment and RED's focus.

6.5 FURTHER RESEARCH NEEDS

The study could contribute to the general organizational possibilities of a RED within the corporate structure and answer whether REDs positively impact a company. In the process, the participating industrial manufacturing companies were considered. Despite the extensive research already carried out, there is still a considerable need for research in this area. More detailed research is needed on how the forms of organization differ in the individual industries. The differences between large-, small-, and medium-sized enterprises must be scrutinized in more detail. Do small companies also have REDs in a form comparable to those of large industrial companies? If not, why not? If so, how do they differ in goals, organization, and activities from bigger industrial companies?

Another point to consider is the tasks assigned to a RED. What are the actual reasons that have led to different tasks being assigned to REDs? Likewise, the entire calculative structure of a RED within the company organization should be looked at in detail. It is also an open question as to what the decisive factors are that quickly make an introduced RED an essential pillar of a company. Furthermore, it must be determined how many staff with which qualifications the RED of a company must have concerning the company's size and turnover in order for the RED to work as efficiently as possible. Another question that remains unanswered is why, despite the economic disadvantages, there are still maintenance departments today that work exclusively or at least partially reactively.

Overall, the research shows that reliability engineering in industrial manufacturing companies is complex and multifaceted. To dive even deeper into the topic of REDs, further research and analysis are needed to consider the specific circumstances and challenges in different industries and company sizes.

Due to the design of the presented study, the results obtained can only be transferred to the generality of companies to a limited extent. In order to be able to generalize the results obtained, the hypotheses developed must be confirmed or refuted in a large-scale quantitative study.

6.6 OUTLOOK

This thesis has highlighted the potential advantages of establishing a dedicated reliability engineering department within a company, with an emphasis on cost reduction. Nevertheless, it is crucial to acknowledge that the integration of a RED can vary distinctively depending on specific company factors. This variability emphasizes the need for manufacturing companies to carefully assess the implementation of such a department and thoroughly evaluate the cost-benefit aspects of this decision. It is also important to note that this study did not specifically address small and medium-sized enterprises (SMEs), leaving the applicability of a RED in these contexts uncertain. Additionally, the research did not explore whether the benefits of a RED are consistent across different industrial sectors, as varying sectoral needs and priorities could influence the role and effectiveness of a RED.

One critical consideration is the rapid advancement of digitalization in the manufacturing industry. This ongoing digital transformation is expected to bring significant changes to many areas of manufacturing operations, potentially impacting the scope and focus of a RED's activities. For example, a RED may increasingly focus on leveraging digital technologies to improve efficiency and drive innovation. In addition, as companies seek to become more environmentally responsible, REDs will likely need to shift their focus to the efficient use of renewable energy, which aligns with broader sustainability goals and regulatory requirements. The continued evolution of technological innovations may also require a shift in RED's priorities and activities, requiring the department to adapt and integrate new technologies to remain competitive in the rapidly changing manufacturing landscape.

The rise of artificial intelligence is also expected to introduce new methods for evaluating and monitoring production machinery, although the extent and impact of these developments are not yet fully understood. Given these factors, it is expected that more companies will explore the establishment of a dedicated RED and subsequently integrate it into their organizational structure. This trend suggests that the number of REDs in the manufacturing industry is likely to increase soon as companies strive to adapt, innovate, and maintain their competitive edge in a dynamic business environment.

7 REFERENCES

- Adu, J., Owusu, M. F., Martin-Yeboah, E., Pino Gavidia, L. A., & Gyamfi, S. (2022). A discussion of some controversies in mixed methods research for emerging researchers. *Methodological Innovations*, 15(3), 321–330. <https://doi.org/10.1177/20597991221123398>
- Alfatih, M. S. S., Leong, M. S., & Hee, L. M. (2015). Definition of Engineering Asset Management: a Review. *Applied Mechanics and Materials*, 773–774(2015), 794–798. <https://doi.org/10.4028/www.scientific.net/AMM.773-774.794>
- Altehmazi, M. M., Suliman, S. M. A., & Alalawi, Y. (2017). An Optimization Approach to the Preventive Maintenance Planning Process. *Modern Applied Science*, 11(9), 20. <https://doi.org/10.5539/mas.v11n9p20>
- Amadi-Echendu, J. E., Willett, R., Brown, K., Hope, T., Lee, J., Mathew, J., Vyas, N., & Yang, B.-S. (2010). What Is Engineering Asset Management? In J. E. Amadi-Echendu, K. Brown, R. Willett, & J. Mathew (Eds.), *Definitions, Concepts and Scope of Engineering Asset Management* (pp. 3–16). Springer-Verlag London Limited. <https://doi.org/DOI 10.1007/978-1-84996-178-3>
- Arcuri, M. C. (2019). *Asset Management: Strategies, Opportunities and Challenges*. Nova Science Publishers Inc. <https://novapublishers.com/shop/asset-management-strategies-opportunities-and-challenges/>
- Atkinson, R., & Flint, J. (2001). *Accessing Hidden and Hard-to-Reach Populations: Snowball Research Strategies*. <https://sru.soc.surrey.ac.uk/SRU33.html>
- Aven, T. (2017). Improving the foundation and practice of reliability engineering. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*, 231(3), 295–305. <https://doi.org/10.1177/1748006X17699478>
- Bailey, M. (2019). Snowball Sampling in Business Oral History: Accessing and Analyzing Professional Networks in the Australian Property Industry. *Enterprise & Society*, 20(1), 74–88. <https://doi.org/10.1017/eso.2018.110>
- Bannon, W. (2015). Missing data within a quantitative research study: How to assess it, treat it, and why you should care. *Journal of the American*

- Association of Nurse Practitioners*, 27(4), 230–232.
<https://doi.org/10.1002/2327-6924.12208>
- Barberá, L., Crespo, A., Viveros, P., & Stegmaier, R. (2012). Advanced model for maintenance management in a continuous improvement cycle: Integration into the business strategy. *International Journal of Systems Assurance Engineering and Management*, 3(1), 47–63.
<https://doi.org/10.1007/s13198-012-0092-y>
- Baur, N., & Blasius, J. (2019). Methoden der empirischen Sozialforschung – Ein Überblick. In N. Baur & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (2nd ed., pp. 1–28). Springer VS.
<https://doi.org/https://doi.org/10.1007/978-3-658-21308-4>
- Bazeley, P. (2018). “Mixed Methods in my Bones”: Transcending the Qualitative-Quantitative Divide. *INTERNATIONAL JOURNAL OF MULTIPLE RESEARCH APPROACHES*, 10(1), 334–341.
<https://doi.org/10.29034/ijmra.v10n1a22>
- Behringer, S. (2018). *Controlling*. Springer Fachmedien Wiesbaden.
<https://doi.org/10.1007/978-3-658-18380-6>
- Belekoukias, I., Garza-Reyes, J. A., & Kumar, V. (2014). The impact of lean methods and tools on the operational performance of manufacturing organisations. *International Journal of Production Research*, 52(18), 5346–5366.
<https://doi.org/10.1080/00207543.2014.903348>
- Bell, E., Bryman, A., & Harley, B. (2019). *BUSINESS RESEARCH METHODS* (5th ed.). Oxford University Press. www.oup.com;
- Ben-Daya, M., Kumar, U., & Murthy, D. N. P. (2016). *Introduction to Maintenance Engineering: Modeling, Optimization, and Management*. John Wiley & Sons, Ltd.
- Bensmain, Y., Dahane, M., Bennekrouf, M., & Sari, Z. (2019). Optimal preventive remanufacturing planning of production equipment under operational and imperfect maintenance constraints: A hybrid genetic algorithm based approach. *Reliability Engineering & System Safety*, 185, 546–566. <https://doi.org/10.1016/j.ress.2018.09.001>

- Bergmann, M., & Franzese, F. (2020). Fehlende Werte. In *Fortgeschrittene Analyseverfahren in den Sozialwissenschaften* (pp. 165–203). Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-30237-5_6
- Besnard, F., Fischer, K., & Tjernberg, L. B. (2013). A model for the Optimization of the Maintenance Support Organization for Offshore Wind Farms. *IEEE Transactions on Sustainable Energy*, 4(2), 443–450. <https://doi.org/10.1109/TSTE.2012.2225454>
- Best, H., & Wolf, C. (2010). Einführung: Sozialwissenschaftliche Datenanalyse. In C. Wolf & H. Best (Eds.), *Handbuch der sozialwissenschaftlichen Datenanalyse* (pp. 3–8). VS Verlag für Sozialwissenschaften/Springer Fachmedien. <https://doi.org/10.1007/978-3-531-92038-2>
- Birolini, A. (2017). *Reliability Engineering: Theory and Practice* (8th ed.). Springer-Verlag GmbH. <https://doi.org/10.1007/978-3-662-54209-5>
- Blischke, W. R., & Murthy, D. N. P. (2000). *Reliability: Modeling, Prediction, and Optimization*. John Wiley & Sons, Inc.
- Blischke, W. R., & Murthy, D. N. P. (2003). Introduction and Overview. In W. R. Blischke & D. N. P. Murthy (Eds.), *Case Studies in Reliability and Maintenance* (pp. 1–34). John Wiley & Sons, Inc.
- Bohlin, M., & Wärja, M. (2015). Maintenance optimization with duration-dependent costs. *Annals of Operations Research*, 224(1), 1–23. <https://doi.org/10.1007/s10479-012-1179-1>
- Bortz, J., & Döring, N. (2006). *Forschungsmethoden und Evaluation für Human- und Sozialwissenschaftler* (4th ed.). Springer Medizin Verlag. <https://doi.org/10.1007/978-3-540-33306-7>
- Bos, J. (2020). *Research Ethics for Students in the Social Sciences*. Springer Nature Switzerland AG. <https://doi.org/10.1007/978-3-030-48415-6>
- Braglia, M., Fantoni, G., & Frosolini, M. (2007). The house of reliability. *International Journal of Quality & Reliability Management*, 24(4), 420–440. <https://doi.org/10.1108/02656710710740572>
- Brandt, H., & Moosbrugger, H. (2020). Planungsaspekte und Konstruktionsphasen von Tests und Fragebogen. In *Testtheorie und Fragebogenkonstruktion* (pp. 39–66). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-61532-4_3

- Brosius, H.-B., Haas, A., & Koschel, F. (2016). *Methoden der empirischen Kommunikationsforschung* (7th ed.). VS Verlag für Sozialwissenschaften. <https://doi.org/10.1007/978-3-531-19996-2>
- Brühl, R., & Buch, S. (2006). *Einheitliche Gütekriterien in der empirischen Forschung? – Objektivität, Reliabilität und Validität in der Diskussion* (20; ESCP-EAP European School of Management).
- Brumby, L. (2018). Instandhaltung und Asset Management. In J. Reichel, G. Müller, & J. Haefls (Eds.), *Betriebliche Instandhaltung* (2nd ed., pp. 67–90). Springer-Verlag GmbH. [https://doi.org/https://doi.org/10.1007/978-3-662-53135-8_5](https://doi.org/10.1007/978-3-662-53135-8_5)
- Bryman, A. (2016). *Social Research Methods* (5th ed.). Oxford University Press. <http://link.springer.com/10.1007/978-3-319-99118-4>
- Buchholz, L. (2019). *Strategisches Controlling*. Springer Fachmedien Wiesbaden. <https://doi.org/10.1007/978-3-658-26662-2>
- Buck, H. (2017). Aktuelle Unternehmenskonzepte und die Entwicklung der Arbeitsorganisation. In *Neue Entwicklungen in der Unternehmensorganisation* (pp. 57–77). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-55426-5_12
- Bundesdatenschutzgesetz (BDSG) (2021). <https://dejure.org/gesetze/BDSG>
- Bußmann, U., Schweighofer, S., & Panz, R. M. (2013). *Organisational Cultures: Networks, Clusters, Alliances*. Anchor Academic Publishing.
- Calixto, E. (2013). *Gas and Oil Reliability Engineering: Modeling and Analysis*. Elsevier. <https://doi.org/10.1016/B978-0-12-391914-4.00007-1>
- Cantu, J., Gharehyakheh, A., Fritts, S., & Tolk, J. (2021). Assessing the HRO: Tools and techniques to determine the high-reliability state of an organization. *Safety Science*, 134(November 2020). <https://doi.org/10.1016/j.ssci.2020.105082>
- Chen, T.-H., & Bao, C.-P. (2013). Applying cost-reliability analysis to improve system reliability. *Journal of Industrial and Production Engineering*, 30(7), 467–472. <https://doi.org/10.1080/21681015.2013.869511>
- Cloos, P., Viernickel, S., & Weltzien, D. (2021). Mixed-Methods Designs: Eine kritische Reflexion zu Gelingensbedingungen, Restriktionen und

- Überschüssen. *Frühe Bildung*, 10(4), 248–252.
<https://doi.org/10.1026/2191-9186/a000547>
- Coker, D. C. (2022). A Thematic Analysis of the Structure of Delimitations in the Dissertation. *International Journal of Doctoral Studies*, 17, 141–159.
<https://doi.org/10.28945/4939>
- Cowman, S. (1993). Triangulation: a means of reconciliation in nursing research. *Journal of Advanced Nursing*, 18(5), 788–792.
<https://doi.org/10.1046/j.1365-2648.1993.18050788.x>
- Creswell, J. W. (2003). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches* (2nd ed.). SAGE Publications Inc.
- Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4th ed.). SAGE Publications, Inc.
- Creswell, J. W., & Creswell, D. J. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications, Inc.
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and Conducting Mixed Methods Research* (3rd ed.). SAGE Publications Inc.
- Dam, A. E. (2010). Reliability Fundamentals. *SMRP SOLUTIONS*, 14(5), 08–14.
https://doi.org/10.1142/9789814277112_0005
- Daum, A., Greife, W., & Przywara, R. (2010). *BWL für Ingenieure und Ingenieurinnen: Was man über Betriebswirtschaft wissen sollte*. Vieweg+Teubner.
- de Jonge, B., Klingenberg, W., Teunter, R., & Tinga, T. (2016). Reducing costs by clustering maintenance activities for multiple critical units. *Reliability Engineering and System Safety*, 145, 93–103.
<https://doi.org/10.1016/j.ress.2015.09.003>
- Denzin, N. K. (2007). Triangulation. In *The Blackwell Encyclopedia of Sociology*. Wiley. <https://doi.org/10.1002/9781405165518.wbeost050>
- Dietrich, J. R., & Meitinger, T. H. (2021). *Erfinderhandbuch*. Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-662-62909-3>
- Dimitrova, D. (2008). Das Konzept der Metakompetenz. In *Das Konzept der Metakompetenz*. Gabler. https://doi.org/10.1007/978-3-8349-9977-1_4

- DIN Deutsches Institut für Normung e. V. (2015). *Instandhaltung - Instandhaltung im Rahmen des Anlagenmanagements; Deutsche Fassung DIN EN 16646:2014*.
- DIN Deutsches Institut für Normung e. V. (2018). *Instandhaltung – Begriffe der Instandhaltung; Dreisprachige Fassung EN 13306:2017*.
- DIN Deutsches Institut für Normung e. V. (2019). *Grundlagen der Instandhaltung DIN 31051*.
- Dittmar, N. (2004). *Transkription: Ein Leitfaden mit Aufgaben für Studenten, Forscher und Laien* (2nd ed.). VS Verlag für Sozialwissenschaften/GMV Fachverlage GmbH.
- Drost, E. A. (2011). Validity and Reliability in Social Science Research. *Education Research and Perspectives*, 38(1), 105–124.
- Easton, K. L., McComish, J. F., & Greenberg, R. (2000). Avoiding Common Pitfalls in Qualitative Data Collection and Transcription. *QUALITATIVE HEALTH RESEARCH*, 10(5), 703–707. <https://doi.org/10.1177/104973200129118651>
- Ebeling, C. E. (1997). *Introduction to Reliability & Maintainability Engineering*. McGraw-Hill.
- Elsayed, E. A. (2021). *Reliability Engineering* (3rd ed.). John Wiley & Sons, Inc.
- Emblemsvåg, J., & Tonning, L. (2003). Decision support in selecting maintenance organization. *Journal of Quality in Maintenance Engineering*, 9(1), 11–24. <https://doi.org/10.1108/13552510310466765>
- Enders, C. K. (2010). *Applied Missing Data Analysis*. The Guilford Press.
- Engel, U., & Schmidt, B. O. (2019). Unit- und Item-Nonresponse. In *Handbuch Methoden der empirischen Sozialforschung* (pp. 385–404). Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-21308-4_27
- Erbe, H., Iung, B., & Morel, G. (2007). Maintenance Models and Services – A Survey Regarding Cost Aspects. *IFAC Proceedings Volumes*, 40(1), 130–141. <https://doi.org/10.3182/20070213-3-CU-2913.00023>
- Eti, M. C., Ogaji, S. O. T., & Probert, S. D. (2006). Reducing the cost of preventive maintenance (PM) through adopting a proactive reliability-focused

- culture. *Applied Energy*, 83(11), 1235–1248. <https://doi.org/10.1016/j.apenergy.2006.01.002>
- European Commission (Ed.). (2010). *European Textbook on Ethics in Research*. Publications Office of the European Union. <https://doi.org/10.1177/174701611100700209>
- European Commission (Ed.). (2013). *Ethics for researchers*. Publications Office of the European Union. <https://doi.org/10.2777/7491>
- European Commission – Eurostat. (2021). *Glossary: Enterprise Size*. https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Enterprise_size
- Faddoul, R., Raphael, W., & Chateauneuf, A. (2018). Maintenance optimization of series systems subject to reliability constraints. *Reliability Engineering and System Safety*, 180(July), 179–188. <https://doi.org/10.1016/j.res.2018.07.016>
- Farahani, A., & Tohidi, H. (2021). Integrated optimization of quality and maintenance: A literature review. *Computers and Industrial Engineering*, 151. <https://doi.org/10.1016/j.cie.2020.106924>
- Fiedler, R., & Gräf, J. (2012). *Einführung in das Controlling: Methoden, Instrumente und IT-Unterstützung* (3rd ed.). Oldenbourg Wissenschaftsverlag GmbH.
- Fink, A. (2014). *CONDUCTING RESEARCH LITERATURE REVIEWS: From the Internet to Paper* (4th ed.). SAGE Publications Inc.
- Flick, U. (2011). *Triangulation: Eine Einführung* (3rd ed.). VS Verlag für Sozialwissenschaften/Springer Fachmedien. <https://doi.org/10.1007/978-3-531-92864-7>
- Flick, U. (2019). Gütekriterien qualitativer Sozialforschung. In N. Baur & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (2nd ed., pp. 473–488). Springer VS. https://doi.org/https://doi.org/10.1007/978-3-658-21308-4_33
- Flick, U. (2022). *DOING INTERVIEW RESEARCH*. SAGE Publications Ltd.
- Fowler, F. J. (2014). *Survey Research Methods* (5th ed.). SAGE Publications, Inc.

- General Data Protection Regulation (2016). <http://data.consilium.europa.eu/doc/document/ST-5419-2016-INIT/en/pdf>
- Glaser, B. G., & Strauss, A. L. (2010). *Grounded Theory: Strategien qualitativer Forschung* (3rd ed.). Verlag Hans Huber, Hogrefe AG.
- Gläser, J., & Laudel, G. (2009). *Experteninterviews und qualitative Inhaltsanalyse als Instrumente rekonstruierender Untersuchungen* (3rd ed.). VS Verlag für Sozialwissenschaften/GWV Fachverlage GmbH. http://books.google.com/books?id=2a1fZ8YU0_oC&pgis=1
- Gläser, M. (2014). *Medienmanagement* (3rd ed.). Vahlen.
- Gläser-Zikuda, M. (2011). Qualitative Auswertungsverfahren. In H. Reinders, H. Ditton, C. Gräsel, & B. Gniewosz (Eds.), *Empirische Bildungsforschung: Strukturen und Methoden* (pp. 109–119). VS Verlag für Sozialwissenschaften/Springer Fachmedien Wiesbaden GmbH. https://doi.org/10.1007/978-3-531-93015-2_9
- Gohres, H.-W., & Reichel, J. (2018). Chronik der Instandhaltung – Schlaglichter einer Entwicklung. In J. Reichel, G. Müller, & J. Haeffs (Eds.), *Betriebliche Instandhaltung* (2nd ed., pp. 3–12). Springer Vieweg. <https://doi.org/https://doi.org/10.1007/978-3-662-53135-8>
- Grecu, A. L., & Völcker, M. (2018). Mixed Methods - Potenziale und Herausforderungen der Integration qualitativer und quantitativer Forschungsmethoden. In *Qualitative Bildungsforschung - Methodische und methodologische Herausforderungen in der Forschungspraxis* (pp. 229–246). Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-18597-8_13
- Guest, G., Bunce, A., & Johnson, L. (2006). How Many Interviews Are Enough? *Field Methods*, 18(1), 59–82. <https://doi.org/10.1177/1525822X05279903>
- Hafidi, N., El Barkany, A., El Mhamedi, A., & Mahmoudi, M. (2020). Integrated planning of production and maintenance for imperfect system with subcontracting strategies. *International Journal of Engineering Business Management*, 12, 1–14. <https://doi.org/10.1177/1847979020929783>
- Hammersley, M. (2008). Troubles with Triangulation. In M. M. Bergman (Ed.), *Advances in Mixed Methods Research* (pp. 22–36). Sage. <https://www.researchgate.net/publication/42800716>

- Haroun, A. E., & Duffuaa, S. O. (2009). Maintenance Organization. In M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, & D. Ait-Kadi (Eds.), *Handbook of Maintenance Management and Engineering* (pp. 3–16). Springer-Verlag London Limited. <https://doi.org/DOI.10.1007/978-1-84882-472-0>
- Hasanah, I. S., & Wulandari, R. (2019). Optimization preventive maintenance of equipment production on palm oil mill. *IOP Conference Series: Materials Science and Engineering*, 505(1). <https://doi.org/10.1088/1757-899X/505/1/012155>
- Hauser, C., Simonyan, A., & Werner, A. (2021). Condoning Corrupt Behavior at Work: What Roles Do Machiavellianism, On-the-Job Experience, and Neutralization Play? *Business & Society*, 60(6), 1468–1506. <https://doi.org/10.1177/0007650319898474>
- Hawkins, B. (2015). The Financial Benefits of Reliability. *Industrial Maintenance & Plant Operation*, 76(3), 30–31.
- Heiser, P. (2018). *Meilensteine der qualitativen Sozialforschung*. Springer Fachmedien Wiesbaden. <https://doi.org/10.1007/978-3-658-18557-2>
- Helfferrich, C. (2019). Leitfaden- und Experteninterviews. In N. Baur & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (2nd ed., pp. 669–686). Springer VS. https://doi.org/https://doi.org/10.1007/978-3-658-21308-4_44
- Hennink, M., & Kaiser, B. N. (2022). Sample sizes for saturation in qualitative research: A systematic review of empirical tests. *Social Science and Medicine*, 292. <https://doi.org/10.1016/j.socscimed.2021.114523>
- Hering, E. (2014). *Controlling für Ingenieure*. Springer Vieweg. <https://doi.org/10.1007/978-3-658-04369-8>
- Hodapp, W. (2018). Die Bedeutung einer zustandsorientierten Instandhaltung. In J. Reichel, G. Müller, & J. Haeffs (Eds.), *Betriebliche Instandhaltung* (2nd ed., pp. 135–152). Springer Vieweg. <https://doi.org/https://doi.org/10.1007/978-3-662-53135-8>
- Huber, C. (2018). Infrarot-Thermografie in der Instandhaltung der chemischen Industrie. In J. Reichel, G. Müller, & J. Haeffs (Eds.), *Betriebliche Instandhaltung* (2nd ed., pp. 239–254). Springer Vieweg. <https://doi.org/https://doi.org/10.1007/978-3-662-53135-8>

- Idhammar, C. (2009). Cut Costs or Improve Reliability? *Pulp & Paper International (PPI)*, 51(4), 27–29.
- Ito, K., & Nakagawa, T. (2009). Applied Maintenance Models. In M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, & D. Ait-Kadi (Eds.), *Handbook of Maintenance Management and Engineering* (pp. 363–396). Springer-Verlag London Limited. <https://doi.org/DOI.10.1007/978-1-84882-472-0>
- Jardine, A. K. S., & Tsang, A. H. C. (2013). *Maintenance, Replacement, and Reliability: Theory and Applications* (2nd ed.). Taylor & Francis Group.
- Jensen, U. (2012). Leitlinien zum Management von Forschungsdaten: Sozialwissenschaftliche Umfragedaten. In *GESIS-Technical Reports*. http://www.gesis.org/fileadmin/upload/forschung/publikationen/gesis_reihen/gesis_methodenberichte/2012/TechnicalReport_2012-07.pdf
- Jin, T. (2019). *Reliability Engineering and Services*. John Wiley & Sons Ltd. <https://doi.org/10.1002/9781118700228.scard>
- Jones, G. R. (2013). *Organizational Theory, Design, and Change* (7th ed.). Pearson Education Limited.
- Jungbauer-Gans, M. (2009). Geleitwort. In P. Kriwy & C. Gross (Eds.), *Klein aber fein! Quantitative empirische Sozialforschung mit kleinen Fallzahlen* (p. 6). VS Verlag für Sozialwissenschaften/GWV Fachverlage GmbH. https://doi.org/10.1007/978-3-531-91380-3_1
- Kaiser, R. (2014). *Qualitative Experteninterviews: Konzeptionelle Grundlagen und praktische Durchführung*. Springer Fachmedien. <https://doi.org/10.1007/978-3-658-02479-6>
- Kapur, K. C., & Pecht, M. (2014). *Reliability Engineering*. John Wiley & Sons, Inc.
- Kareem, J. A. H., Saeed, K. F. A., & Faraj, O. M. M. (2019). Maintenance Practices in Poor Uptime of Operating Equipment Toward Dynamic of Business Issues. *International Journal of Innovation and Technology Management*, 16(2), 1–21. <https://doi.org/10.1142/S0219877019500172>
- Kececioglu, D. (2002). *Reliability Engineering Handbook Volume 1*. DEStech Publications book.

- Kilic, E., Ali, S. S., Weber, G. W., & Dubey, R. (2014). A value-adding approach to reliability under preventive maintenance costs and its applications. *Optimization: A Journal of Mathematical Programming and Operations Research*, 63(12), 1805–1816. <https://doi.org/10.1080/02331934.2014.917301>
- Kimera, D., & Nangolo, F. N. (2020). Maintenance optimization for marine mechanical systems. *Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment*, 234(2), 446–462. <https://doi.org/10.1177/1475090219882601>
- Kiran, D. R. (2017). *Total Quality Management: Key Concepts and Case Studies*. Butterworth-Heinemann. <https://doi.org/https://doi.org/10.1016/C2016-0-00426-6>
- Kiran, S., Prajeeth Kumar, K. P., Sreejith, B., & Muralidharan, M. (2016). Reliability evaluation and Risk based maintenance in a process plant. *Procedia Technology*, 24, 576–583. <https://doi.org/10.1016/j.protcy.2016.05.117>
- Kirchhoff, S., Kuhnt, S., Lipp, P., & Schlawin, S. (2010). Der Fragebogen: Datenbasis, Konstruktion und Auswertung. In *Fragebogen* (5th ed.). VS Verlag für Sozialwissenschaften / Springer Fachmedien Wiesbaden GmbH. http://link.springer.com/10.1007/978-3-663-10087-4_3
- Knapp, G. M., & Mahajan, M. (1998). Optimization of maintenance organization and manpower in process industries. *Journal of Quality in Maintenance Engineering*, 4(3), 168–183. <https://doi.org/10.1108/13552519810223472>
- König, J. (2016). Praxisforschung in Zwölf Arbeitsschritten: Handlungswissen im Überblick. In *Praxisforschung in der Sozialen Arbeit*. W. Kohlhammer GmbH.
- Korndörfer, W. (1990). Unternehmensführungslehre: Einführung, Entscheidungslogik, soziale Kompetenzen im Entscheidungsprozess. In *Unternehmensführungslehre* (7th ed.). Gabler Verlag. <https://doi.org/10.1007/978-3-322-83817-9>
- Krebs, D., & Menold, N. (2019). Gütekriterien quantitativer Sozialforschung. In N. Baur & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (2nd ed., pp. 489–504). Springer VS. https://doi.org/https://doi.org/10.1007/978-3-658-21308-4_34

- Kuckartz, U. (2014a). *Mixed Methods: Methodologie, Forschungsdesigns und Analyseverfahren*. Springer VS. <https://doi.org/10.1007/978-3-531-93267-5>
- Kuckartz, U. (2014b). *Qualitative Text Analysis: A Guide to Methods, Practice & Using Software*. SAGE Publications Ltd.
- Kuckartz, U. (2018). *Qualitative Inhaltsanalyse. Methoden, Praxis, Computerunterstützung* (4th ed.). Beltz Juventa.
- Kuckartz, U., & Rädiker, S. (2019). *Analyzing Qualitative Data with MAXQDA: Text, Audio, and Video*. Springer Nature Switzerland AG. <https://doi.org/10.1007/978-3-030-15671-8>
- Lamnek, S., & Krell, C. (2016). *Qualitative Sozialforschung* (6th ed.). Beltz Verlag.
- Lange, B. (2019). Immobilienbestandsmanagement. In K.-U. Brauer (Ed.), *Grundlagen der Immobilienwirtschaft* (10th ed., pp. 479–536). Springer Fachmedien. https://doi.org/https://doi.org/10.1007/978-3-658-21682-5_10
- Liao, W., Chen, M., & Yang, X. (2017). Joint optimization of preventive maintenance and production scheduling for parallel machines system. *Journal of Intelligent and Fuzzy Systems*, 32(1), 913–923. <https://doi.org/10.3233/JIFS-161385>
- Licandro, O., & Puch, L. A. (2000). Capital Utilization, Maintenance Costs and the Business Cycle. *Annales d'Économie et de Statistique*, 58, 143–164. <https://doi.org/10.2307/20076230>
- Lippold, D. (2016). *Organisationsstrukturen von Stabsfunktionen*. Springer Fachmedien Wiesbaden. <https://doi.org/10.1007/978-3-658-12662-9>
- Liu, Q., Dong, M., & Chen, F. F. (2018). Single-machine-based joint optimization of predictive maintenance planning and production scheduling. *Robotics and Computer-Integrated Manufacturing*, 51(1), 238–247. <https://doi.org/10.1016/j.rcim.2018.01.002>
- Liu, X., Wang, W., & Peng, R. (2017). An integrated preventive maintenance and production planning model with sequence-dependent setup costs and times. *Quality and Reliability Engineering International*, 33(8), 2451–2461. <https://doi.org/10.1002/qre.2202>

- Lyu, M. R. (2007). Software Reliability Engineering: A Roadmap. *Future of Software Engineering (FOSE '07)*, June 2007, 153–170. <https://doi.org/10.1109/FOSE.2007.24>
- Mackey, A., & Gass, S. M. (2005). *SECOND LANGUAGE RESEARCH - Methodology and Design*. Lawrence Erlbaum Associates, Inc.
- Madu, C. N. (2000). Competing through maintenance strategies. *International Journal of Quality & Reliability Management*, 17(9), 937–949. <https://doi.org/10.1108/02656710010378752>
- Madu, C. N. (2005). Strategic value of reliability and maintainability management. *International Journal of Quality & Reliability Management*, 22(3), 317–328. <https://doi.org/10.1108/02656710510582516>
- Maji, A., Bhunia, A. K., & Mondal, S. K. (2020). Exploring a production-inventory model with optimal reliability of the production in a parallel-series system. *Journal of Industrial and Production Engineering*, 37(2–3), 71–86. <https://doi.org/10.1080/21681015.2020.1733109>
- Marchi, B., Zaroni, S., & Jaber, M. Y. (2019). Economic production quantity model with learning in production, quality, reliability and energy efficiency. *Computers and Industrial Engineering*, 129(February), 502–511. <https://doi.org/10.1016/j.cie.2019.02.009>
- Marek, D. (2020). Organisationsdesign. In *Organisationsdesign*. Springer Fachmedien Wiesbaden. <https://doi.org/10.1007/978-3-658-27673-7>
- Marr, Bernard. (2012). *Key Performance Indicators : The 75 measures every manager needs to know*. Pearson Financial Times Publishing.
- Mayring, P. (2000). Qualitative Content Analysis. *Forum Qualitative Sozialforschung*, 1(2), 1–10.
- Mayring, P. (2001). Kombination und Integration qualitativer und quantitativer Analyse. *Forum: Qualitative Sozialforschung*, 2(1).
- Mayring, P. (2007). On Generalization in Qualitatively Oriented Research. *Forum: Qualitative Social Research*, 8(3). <https://doi.org/https://doi.org/10.17169/fqs-8.3.291>
- Mayring, P. (2015). *Qualitative Inhaltsanalyse: Grundlagen und Techniken* (12th ed.). Beltz Verlag.

- McKim, C. A. (2017). The Value of Mixed Methods Research: A Mixed Methods Study. *Journal of Mixed Methods Research*, 11(2), 202–222. <https://doi.org/10.1177/1558689815607096>
- Misoch, S. (2019). *Qualitative Interviews* (2nd ed.). Walter de Gruyter GmbH. <https://doi.org/10.1515/9783110545982>
- Moosbrugger, H., & Kelava, A. (2020). Qualitätsanforderungen an Tests und Fragebogen („Gütekriterien“). In *Testtheorie und Fragebogenkonstruktion* (pp. 13–38). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-61532-4_2
- Morgan, D. L., & Hoffman, K. (2018). Focus Groups. In U. Flick (Ed.), *The SAGE Handbook of Qualitative Data Collection* (pp. 250–263). SAGE Publications Ltd.
- Morse, J. M. (2015). Data were saturated... *Qualitative Health Research*, 25(5), 587–588. <https://doi.org/10.1177/1049732315576699>
- Moubray, J. (1997). *Reliability-centered Maintenance* (2nd ed.). Butterworth-Heinemann.
- Murray, M. (2018). Narrative Data. In U. Flick (Ed.), *The SAGE Handbook of Qualitative Data Collection* (pp. 264–279). SAGE Publications Ltd.
- Nakagawa, T. (2005). *Maintenance Theory of Reliability*. Springer-Verlag London Limited.
- Nakajima, S. (1988). *Introduction to TPM: Total Productive Maintenance*. Productivity Press, Inc.
- Navas, M. A., Sancho, C., & Carpio, J. (2020). Disruptive Maintenance Engineering 4.0. *International Journal of Quality & Reliability Management*, 37(6/7), 853–871. <https://doi.org/10.1108/IJQRM-09-2019-0304>
- Nilchian, S., Majrouhi Sardroud, J., Darabpour, M., & Tavousi Tafreshi, S. (2022). Features and Conditions of Building Information Modeling Contracts. *Buildings*, 12(11). <https://doi.org/10.3390/buildings12111839>
- O'Connor, P. D. T., & Kleyner, A. (2012). *Practical Reliability Engineering* (5th ed.). John Wiley & Sons, Ltd.
- Olawumi, T. O., & Chan, D. W. M. (2021). Developing project evaluation models for smart sustainable practices implementation in construction

- projects: a comparative study between Nigeria and Hong Kong. *Engineering, Construction and Architectural Management*, 29(3), 1522–1552. <https://doi.org/10.1108/ECAM-11-2020-0906>
- Paprocka, I., Kempa, W. M., & Skołud, B. (2021). Predictive maintenance scheduling with reliability characteristics depending on the phase of the machine life cycle. *Engineering Optimization*, 53(1), 165–183. <https://doi.org/10.1080/0305215X.2020.1714041>
- Patton, M. Q. (2015). *Qualitative Research & Evaluation Methods* (4th ed.). SAGE Publications, Inc.
- Pawellek, G. (2016). *Integrierte Instandhaltung und Ersatzteillogistik: Vorgehensweisen, Methoden, Tools* (2nd ed.). Springer Vieweg. <https://doi.org/10.1007/978-3-662-48667-2>
- Porst, R. (1998). *Im Vorfeld der Befragung: Planung, Fragebogenentwicklung, Pre-testing* (1998/02). <https://nbn-resolving.org/urn:nbn:de:0168-ssoar-200484%0ANutzungsbedingungen>:
- Porst, R. (2000). *Question Wording – Zur Formulierung von Fragebogen-Fragen* (2; GESIS-How-To). <https://nbn-resolving.org/urn:nbn:de:0168-ssoar-201334>
- Porst, R. (2014). *Fragebogen: Ein Arbeitsbuch* (4th ed.). Springer VS. <https://doi.org/10.1007/978-3-658-02118-4>
- Porst, R. (2019). Frageformulierung. In N. Baur & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (2nd ed., pp. 829–842). Springer VS. https://doi.org/https://doi.org/10.1007/978-3-658-21308-4_57
- Porter, M. E. (1979). How Competitive Forces Shape Strategy. *Harvard Business Review*.
- Prüß, H., & Diehl, H. (2009). Umsetzung einer ganzheitlichen Assetmanagementstrategie. *ZWF Zeitschrift Für Wirtschaftlichen Fabrikbetrieb*, 104(10), 864–870. <https://doi.org/10.3139/104.110165>
- Przyborski, A., & Wohlrab-Sahr, M. (2014). *Qualitative Sozialforschung: Ein Arbeitsbuch* (4th ed.). Oldenbourg Wissenschaftsverlag GmbH.
- Raaijmakers, Q. A. W. (1999). Effectiveness of Different Missing Data Treatments in Surveys with Likert-Type Data: Introducing the Relative Mean

- Substitution Approach. *Educational and Psychological Measurement*, 59(5), 725–748. <https://doi.org/10.1177/0013164499595001>
- Rädiker, S., & Kuckartz, U. (2020). *Focused Analysis of Qualitative Interviews With MAXQDA: Step by Step*. MAXQDA Press.
- Raithel, J. (2008). *Quantitative Forschung - Ein Praxiskurs* (2nd ed.). VS Verlag für Sozialwissenschaften/GWV Fachverlage GmbH. <http://library1.nida.ac.th/termpaper6/sd/2554/19755.pdf>
- Reinhardt, S. (2012). Das Zusammenspiel von quantitativer und qualitativer Forschung. *Zeitschrift Für Interpretative Schul- Und Unterrichtsforschung*, 1(1), 231–238. <https://doi.org/10.3224/zisu.v1i1.7254>
- Reliability Engineer Demographics and Statistics in the US*. (2023, July 23). <https://www.zippia.com/reliability-engineer-jobs/demographics/>
- Rivera-Gómez, H., Gharbi, A., Kenné, J. P., Montaña-Arango, O., & Corona-Armenta, J. R. (2020). Joint optimization of production and maintenance strategies considering a dynamic sampling strategy for a deteriorating system. *Computers and Industrial Engineering*, 140(11), 1–18. <https://doi.org/10.1016/j.cie.2020.106273>
- Rosqvist, T., Laakso, K., & Reunanen, M. (2009). Value-driven maintenance planning for a production plant. *Reliability Engineering and System Safety*, 94(1), 97–110. <https://doi.org/10.1016/j.ress.2007.03.018>
- Roulston, K., & Choi, M. (2018). Qualitative Interviews. In U. Flick (Ed.), *The SAGE Handbook of Qualitative Data Collection* (pp. 233–249). SAGE Publications Inc.
- Sailer, J., & Hladík, T. (2021). Consistent Maintenance Management Model: Results of Changes of Maintenance Organisation Structure and Processes. *Manufacturing Technology*, 21(1), 124–131. <https://doi.org/10.21062/mft.2021.019>
- Salganik, M. J., & Heckathorn, D. D. (2004). Sampling and Estimation in Hidden Populations Using Respondent-Driven Sampling. *Sociological Methodology*, 34, 193–239.
- Salonen, A., & Deleryd, M. (2011). Cost of poor maintenance: A concept for maintenance performance improvement. *Journal of Quality in Maintenance Engineering*, 17(1), 63–73. <https://doi.org/10.1108/13552511111116259>

- Saunders, B., Sim, J., Kingstone, T., Baker, S., Waterfield, J., Bartlam, B., Burroughs, H., & Jinks, C. (2018). Saturation in qualitative research: exploring its conceptualization and operationalization. *Quality & Quantity*, 52(4), 1893–1907. <https://doi.org/10.1007/s11135-017-0574-8>
- Schlepphorst, S., Koetter, E. C., Werner, A., Soost, C., & Moog, P. (2020). International assignments of employees and entrepreneurial intentions: the mediating role of human capital, social capital and career prospects. *International Journal of Entrepreneurial Behaviour and Research*, 26(6), 1259–1279. <https://doi.org/10.1108/IJEBr-11-2019-0637>
- Schöneck, N. M., & Voß, W. (2013). *Das Forschungsprojekt: Planung, Durchführung und Auswertung einer quantitativen Studie* (2nd ed.). Springer VS. <https://doi.org/10.1007/978-3-531-19502-5>
- Schreier, M. (2014). Varianten qualitativer Inhaltsanalyse: Ein Wegweiser im Dickicht der Begrifflichkeiten. *Forum Qualitative Sozialforschung*, 15(1). <http://nbn-resolving.de/urn:nbn:de:0114-fqs1401185.%0AView>
- Schreier, M. (2018). Sampling and Generalization. In U. Flick (Ed.), *The SAGE Handbook of Qualitative Data Collection* (pp. 84–98). SAGE Publications Ltd.
- Schumann, S. (2012). *Repräsentative Umfrage: Praxisorientierte Einführung in empirische Methoden und statistische Analyseverfahren* (6th ed.). Oldenbourg Wissenschaftsverlag GmbH.
- Schumann, S. (2018). *Quantitative und qualitative empirische Forschung: Ein Diskussionsbeitrag*. Springer VS. <https://doi.org/10.1007/978-3-658-17834-5>
- Shahraki, A. F., Yadav, O. P., & Vogiatzis, C. (2020). Selective maintenance Optimization for Multi-State Systems Considering Stochastically dependent Components and Stochastic Imperfect Maintenance Actions. *Reliability Engineering and System Safety*, 196(RESS 106738). <https://doi.org/10.1016/j.ress.2019.106738>
- Sharma, H. (2022). How short or long should be a questionnaire for any research? Researchers dilemma in deciding the appropriate questionnaire length. *Saudi Journal of Anaesthesia*, 16(1), 65. https://doi.org/10.4103/sja.sja_163_21
- Siddiqui, A. W., & Ben-Daya, M. (2009). Reliability Centered Maintenance. In M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, & D. Ait-Kadi (Eds.),

- Handbook of Maintenance Management and Engineering* (pp. 397–416). Springer-Verlag London Limited. <https://doi.org/10.1007/978-1-84882-472-0>
- Siew, C. Y., Ong, S. K., & Nee, A. Y. C. (2021). Improving maintenance efficiency and safety through a human-centric approach. *Advances in Manufacturing*, 9(1), 104–114. <https://doi.org/10.1007/s40436-020-00334-x>
- Sinha, P. (2015). Towards higher maintenance effectiveness: Integrating maintenance management with reliability engineering. *International Journal of Quality & Reliability Management*, 32(7), 754–762. <https://doi.org/10.1108/IJQRM-03-2013-0039>
- Skordaki, E.-M., & Bainbridge, S. (2018). Blended Training on Scientific Software: A Study on How Scientific Data are Generated. *The International Review of Research in Open and Distributed Learning*, 19(2). <https://doi.org/10.19173/irrodl.v19i2.3353>
- Sloss, B. T. (2016). Introduction. In B. Beyer, C. Jones, J. Petoff, & N. R. Murphy (Eds.), *Site Reliability Engineering: How Google Runs Production System* (pp. 3–12). O'Reilly Media Inc.
- Smith, D. J. (2011). *Reliability, Maintainability and Risk: Practical Methods for Engineers* (8th ed.). Butterworth-Heinemann.
- Spath, D. (2017). Grundlagen der Organisationsgestaltung. In *Neue Entwicklungen in der Unternehmensorganisation* (pp. 3–29). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-55426-5_1
- Spieß, M. (2010). Der Umgang mit fehlenden Werten. In C. Wolf & H. Best (Eds.), *Handbuch der sozialwissenschaftlichen Datenanalyse* (pp. 117–142). VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-92038-2_6
- Steinborn, G. (2005). Produktionsfaktor Instandhaltung. *Erdöl Erdgas Kohle*, 121(2), 74–80.
- Stockemer, D. (2019). *Quantitative Methods for the Social Sciences*. Springer International Publishing AG. <https://doi.org/10.1007/978-3-319-99118-4>
- Strübing, J. (2014). *Grounded Theory: Zur sozialtheoretischen und epistemologischen Fundierung eines pragmatistischen Forschungsstils* (3rd ed.). Springer VS. <https://doi.org/10.1007/978-3-531-19897-2>

- Strunz, M. (2012). *Instandhaltung: Grundlagen – Strategien – Werkstätten*. Springer Vieweg. <https://doi.org/10.1007/978-3-642-27390-2>
- Tamanacharya, M. T. (1998). *Industrial Engineering And Production Management* (3rd ed.). S. Chand And Company Limited.
- Tan, C. M. (2017). Theory and Practice of Quality and Reliability Engineering in Asia Industry. In C. M. Tan & T. N. Goh (Eds.), *Theory and Practice of Quality and Reliability Engineering in Asia Industry*. Springer Singapore. <https://doi.org/10.1007/978-981-10-3290-5>
- Tannock, J., & Saelem, S. (2007). Manufacturing disruption costs due to quality loss. *International Journal of Quality & Reliability Management*, 24(3), 263–278. <https://doi.org/10.1108/02656710710730861>
- Tashakkori, A., & Teddlie, C. (1998). *Mixed Methodology: Combining Qualitative and Quantitative Approaches*. SAGE Publications Inc.
- Teddlie, C., & Tashakkori, A. (2003). Major Issues and Controversies in the Use of Mixed Methods in the Social and Behavioral Sciences. In C. Teddlie & A. Tashakkori (Eds.), *Handbook of Mixed Methods in Social and Behavioral Research* (pp. 3–50). SAGE Publications Inc.
- Teddlie, C., & Yu, F. (2007). Mixed Methods Sampling: A Typology With Examples. *Journal of Mixed Methods Research*, 1(1), 77–100. <https://doi.org/10.1177/2345678906292430>
- Theofanidis, D., & Fountouki, A. (2018). LIMITATIONS AND DELIMITATIONS IN THE RESEARCH PROCESS. *PERIOPERATIVE NURSING*, 7(3), 155–162. <https://doi.org/10.5281/zenodo.2552022>
- Tiidenberg, K. (2018). Ethics in Digital Research. In U. Flick (Ed.), *The SAGE Handbook of Qualitative Data Collection* (pp. 466–481). SAGE Publications Ltd.
- Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, 14, 207–222.
- Trinczek, R. (2009). How to Interview Managers? Methodical and Methodological Aspects of Expert Interviews as a Qualitative Method in Empirical Social Research. In A. Bogner, B. Littig, & W. Menz (Eds.), *Interviewing Experts* (pp. 203–216). Palgrave Macmillan.

- Truong-Ba, H., Borghesani, P., Cholette, M. E., & Ma, L. (2020). Optimization of condition-based maintenance considering partial opportunities. *Quality and Reliability Engineering International*, 36(2), 529–546. <https://doi.org/10.1002/qre.2585>
- Van den Broeck, J., Cunningham, S. A., Eeckels, R., & Herbst, K. (2005). Data Cleaning: Detecting, Diagnosing, and Editing Data Abnormalities. *PLoS Medicine*, 2(10), 0966–0970. <https://doi.org/10.1371/journal.pmed.0020267>
- Verein Deutscher Ingenieure. (2012). *Organisation der Instandhaltung/Organisation of maintenance VDI 2895*. Beuth Verlag GmbH.
- Vilarinho, S., Lopes, I., & Oliveira, J. A. (2017). Preventive maintenance decisions through maintenance optimization models: a case study. *Procedia Manufacturing*, 11(June), 1170–1177. <https://doi.org/10.1016/j.promfg.2017.07.241>
- Vishnu, C. R., & Regikumar, V. (2016). Reliability Based Maintenance Strategy Selection in Process Plants: A Case Study. *Procedia Technology*, 25, 1080–1087. <https://doi.org/10.1016/j.protcy.2016.08.211>
- Waeyenbergh, G., & Pintelon, L. (2004). Maintenance concept development: A case study. *International Journal of Production Economics*, 89(3), 395–405. <https://doi.org/10.1016/j.ijpe.2003.09.008>
- Wagner-Schelewsky, P., & Hering, L. (2019). Online-Befragung. In N. Baur & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (2nd ed., pp. 787–800). Springer VS. https://doi.org/https://doi.org/10.1007/978-3-658-21308-4_54
- Walle, A. H. (2015). *Qualitative Research in Business: A Practical Overview*. Cambridge Scholars Publishing.
- Wang, W., Lin, M., Fu, Y., Luo, X., & Chen, H. (2020). Multi-objective optimization of reliability-redundancy allocation problem for multi-type production systems considering redundancy strategies. *Reliability Engineering & System Safety*, 193(February 2019), 1–10. <https://doi.org/10.1016/j.ress.2019.106681>
- Weichbold, M. (2019). Pretest. In N. Baur & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (2nd ed., pp. 349–356). Springer VS. https://doi.org/https://doi.org/10.1007/978-3-658-21308-4_23

- White, P. (2009). *Developing Research Questions : A Guide for Social Scientists*. Palgrave Macmillan.
- Wicharz, R. (2018). Strategie: Ausrichtung von Unternehmen auf die Erfolgslogik ihrer Industrie. In *Strategie: Ausrichtung von Unternehmen auf die Erfolgslogik ihrer Industrie* (3rd ed.). Springer Fachmedien Wiesbaden. <https://doi.org/10.1007/978-3-658-18712-5>
- Wichmann, A. (2019). *Quantitative und Qualitative Forschung im Vergleich: Denkweisen, Zielsetzungen und Arbeitsprozesse*. Springer. <https://doi.org/10.1007/978-3-662-59817-7>
- Williamson, J. (2017). *Downtime costs UK manufacturers £180bn a year*. The Manufacturer. <https://www.themanufacturer.com/articles/machine-downtime-costs-uk-manufacturers-180bn-year/>
- Zepke, G. (2016). *Lust auf qualitative Forschung! Eine Einführung für die Praxis*. T.S.O. Texte zur Systemischen Organisationsforschung.
- Zhou, X., & Yu, M. (2020). Semi-dynamic maintenance scheduling for multi-station series systems in multi-specification and small-batch production. *Reliability Engineering and System Safety*, 195(11), 1–9. <https://doi.org/10.1016/j.ress.2019.106753>

8 APPENDICES

8.1 THE "10 COMMANDMENTS" OF QUESTION FORMULATION

1. You shall use simple, unambiguous terms that are understood in the same way by all respondents!
2. You should avoid long and complex questions!
3. You should avoid hypothetical questions!
4. You should avoid double stimuli and negations!
5. You should avoid insinuations and suggestive questions!
6. You should avoid questions that aim at information that many respondents presumably do not have!
7. You should use questions with a precise time reference!
8. You should use answer categories that are exhaustive and disjunctive (free of overlapping)!
9. You shall make sure that the context of a question does not affect its answer!
10. You shall define unclear terms! (Porst, 2000, 2019)

8.2 EXEMPLARY SEARCH PROCEDURE LITERATURE ANALYSIS

English					
Source	Search term	Search mode	Number of hits	Inclusion criteria / exclusion criteria	Comments
EBSCO Discovery Service	maintenance	all fields	7,773,408	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	maintenance AND organization	all fields	1,972,310	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	maintenance AND organization AND costs	all fields	1,129,444	too many non-relevant results	refine search, limit search fields
EBSCO Discovery Service	maintenance AND organization	keywords	33,631	too many non-relevant results	refine search, limit search fields
EBSCO Discovery Service	maintenance AND organization AND costs	keywords	3,345	too many non-relevant results	refine search, limit search fields
EBSCO Discovery Service	maintenance AND organization	title	2,815	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	maintenance AND organization AND costs	title	895	results might be too much	refine search, combine search terms, limit search fields
EBSCO Discovery Service	maintenance AND organization AND cost-efficiency	all fields	26,402	too many non-relevant results	refine search, limit search fields
EBSCO Discovery Service	maintenance AND organization AND cost-efficiency	keywords	6	insufficient results	no further restriction of the search
German					
Source	Search term	Search mode	Number of hits	Inclusion criteria / exclusion criteria	Comments
EBSCO Discovery Service	Instandhaltung	all fields	32,912	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	Instandhaltung AND Organisation	all fields	22,938	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	Instandhaltung AND Organisation AND Kosten	all fields	4,202	too many non-relevant results	refine search, limit search fields
EBSCO Discovery Service	Instandhaltung AND Organisation	keywords	40	results may not be sufficient	refine search, combine search terms
EBSCO Discovery Service	Instandhaltung AND Organisation AND Kosten	keywords	2	insufficient results	refine search, limit search fields
EBSCO Discovery Service	Instandhaltung AND Organisation	title	16	insufficient results	refine search, combine search terms
EBSCO Discovery Service	Instandhaltung AND Organisation AND Kosten	title	1	insufficient results	no further restriction of the search

English					
Source	Search term	Search mode	Number of hits	Inclusion criteria / exclusion criteria	Comments
EBSCO Discovery Service	business administration	all fields	3,818,665	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	business administration AND savings	all fields	631,247	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	business administration AND savings AND increasing profits	all fields	174,017	too many non-relevant results	refine search, limit search fields
EBSCO Discovery Service	business administration	keywords	81,606	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	business administration AND savings	keywords	234	results may not be sufficient	refine search, combine search terms
EBSCO Discovery Service	business administration AND savings AND increasing profits	keywords	6	insufficient results	refine search, limit search fields
EBSCO Discovery Service	business administration	title	5,563	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	business administration AND savings	title	3	insufficient results	no further restriction of the search

German					
Source	Search term	Search mode	Number of hits	Inclusion criteria / exclusion criteria	Comments
EBSCO Discovery Service	Betriebswirtschaftslehre	all fields	131,887	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	Betriebswirtschaftslehre AND Einsparungen	all fields	1,923	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	Betriebswirtschaftslehre AND Einsparungen AND Gewinnsteigerung	all fields	172	results may not be sufficient	refine search, limit search fields
EBSCO Discovery Service	Betriebswirtschaftslehre	keywords	4,424	too many non-relevant results	refine search, combine search terms
EBSCO Discovery Service	Betriebswirtschaftslehre AND Einsparungen	keywords	0	insufficient results	refine search, combine search terms
EBSCO Discovery Service	Betriebswirtschaftslehre AND Gewinnsteigerung	keywords	0	insufficient results	refine search, limit search fields
EBSCO Discovery Service	Betriebswirtschaftslehre	title	1,365	results might be too much	refine search, combine search terms
EBSCO Discovery Service	Betriebswirtschaftslehre AND Einsparungen	title	0	insufficient results	no further restriction of the search

[illegible]

8.3 QUESTIONNAIRE PRELIMINARY QUANTITATIVE ONLINE SURVEY



UCAM
UNIVERSIDAD
CATÓLICA DE MURCIA



Organization of Reliability Engineering

Start

Dear Sir or Madam,

Thank you for participating in this online survey. Your participation is greatly appreciated and valuable!

This survey is part of a research project in the context of a doctoral thesis with the Universidad Católica San Antonio de Murcia (UCAM), Spain and the FOM University Essen, Germany.

This online survey is anonymous. No connection data will be stored from you.

For questions you can't answer exactly, please estimate as best you can.

If you have any questions about this online survey, please do not hesitate to contact me at: UweBussmann@gmx.de

With kind regards

Uwe Bussmann Dipl.-Ing., MBA

Instructions for completing the survey:

Completion time: approx. 10 minutes

Page 2

1. You are active as? *

- ☐ General Manager
- ☐ Site Manager
- ☐ Production Manager
- ☐ Maintenance Manager
- ☐ Reliability Manager
- ☐ Reliability Engineer
- ☐ Other (please specify)

Page 3

2. In which country is your site? *

Page 4

3. Number of employees at your site? *

If you do not know the exact number, please estimate as best as you can.

4. How many of them work in maintenance? *

If you do not know the exact number, please estimate as best as you can.

5. How many of them work in the area of Reliability Engineering? *

If you do not know the exact number, please estimate as best as you can.

6. How many of the employees in Reliability Engineering have a university degree? *

If you do not know the exact number, please estimate as best as you can.

Page 5

7. Does your site have its own Reliability Engineering department? *

☐ yes

☐ no

Page 6

8. Is your organization planning to establish a separate Reliability Engineering department? *

☐ yes

☐ no

Page 7

9. To which department does Reliability Engineering belong? *

☐ Maintenance

☐ Production

☐ Site Manager

☐ Other (please specify)

Page 8

10. To whom does the Head of Reliability Engineering report? *

☐ General Manager

☐ Site Manager

☐ Production Manager

☐ Maintenance Manager

☐ Other (please specify)

Page 9

11. Which maintenance strategy is pursued? *

More than one answer is possible.

- ☐ Reactive
- ☐ Preventive
- ☐ Predictive
- ☐ Other (please specify)

Page 10

12. Can Reliability Engineering implement savings projects on its own, or does it need the approval of a manager (e.g. Asset Manager, Plant Manager, etc.)? *

- ☐ yes
- ☐ no
- ☐ partly

Page 11

13. From your experience, is this organization purposeful and reasonable? *

- ☐ yes
- ☐ no

Page 12

14. From your perspective, what should the Reliability Engineering organization look like? *

Free-text input.

Page 13

15. Do the employees in Reliability Engineering deal exclusively with plant improvement topics, or do they also take on other tasks? *

- ☐ yes, plant improvement only
☐ no, also other topics

Page 14

16. Which proportion of time is spent on other activities? *

If you do not know the exact number, please estimate as best as you can.

 %

Page 15

17. Which activities in Reliability Engineering do the employees in this area mainly perform? *

More than one answer is possible.

- ☐ Evaluation of data (e.g. SAP, machine data, etc.)
- ☐ Creation of statistics
- ☐ Measurement of machine data (e.g. temperature, vibration, etc.)
- ☐ Hydrocarbon management
- ☐ FMEA / RCA etc.
- ☐ First Time Right, mechanical instruction plans etc.
- ☐ Consulting of the production management
- ☐ Consulting of the production staff
- ☐ Consulting of the maintenance management
- ☐ Consulting of maintenance staff
- ☐ Project Management (for plant improvements)
- ☐ Others (please specify)

Page 16

18. Does Reliability Engineering have its own budget for implementing improvement measures? *

- ☐ yes
- ☐ no

Page 17

19. What percentage of the maintenance budget is spent on reliability measures? *

If you do not know the exact number, please estimate as best as you can.

%

Page 18

20. Has Reliability Engineering already contributed to a cost reduction at your site? *

☐ yes

☐ no

Page 19

21. Reduction in production losses (in percent)? *

If you do not know the exact number, please estimate as best as you can.

	2019	2020
Expectation		
Actual savings		

22. Reduction in maintenance costs (in percent)? *

If you do not know the exact number, please estimate as best as you can.

	2019	2020
Expectation		
Actual savings		

23. Extension of plant operating time (in percent)? *

If you do not know the exact number, please estimate as best as you can.

	2019	2020
Expectation		
Actual savings		

Page 20

24. What potential savings do you or your organization expect in the future? *

If you do not know the exact number, please estimate as best as you can.

Reduction in production losses (in percent)

Reduction in maintenance costs (in percent)

Extension of plant operating time (in percent)

Page 21

25. Which key performance indicators (KPIs) are used to assess the efficiency of Reliability Engineering in your company? *

More than one answer is possible.

☐ Maintenance costs

☐ Production losses

☐ Plant uptime

☐ Others (please specify)

Page 22

26. Does Reliability Engineering actually reach the given targets? *

More than one answer is possible.

☐ Maintenance costs

☐ Production losses

☐ Plant Uptime

☐ Others (please specify)

You have reached the end of the survey.

I would like to thank you very much for your time and effort!

If you have any further questions, please feel free to contact me at: UweBussmann@gmx.de

With kind regards

Uwe Bussmann

You can now close the window.

8.4 CODEBOOK QUANTITATIVE PRELIMINARY STUDY

Variable name	Variable label	Value	Value label
Q1.Job	1. You are active as?	1	General Manager
		2	Site Manager
		3	Production Manager
		4	Maintenance Manager
		5	Reliability Manager
		6	Reliability Engineer
		7	Engineering Manager
		8	Others
Q2.Country	2. In which country is your site?	None	None
E.Continent	Which Continent	1	Europe
		2	Asia
		3	Australia
		4	North America
		5	South America
		6	Africa
Q3.EmpSite	3. Number of employees at your site	None	None
E.CompSize	Company Size	1	micro enterprise (<10 emp)
		2	small enterprise (10-49 emp)
		3	medium-sized enterprise (50-249 emp)
		4	large enterprise (250 and more emp)
Q4.EmpMTCE	4. How many of them work in maintenance?	None	None
Q5.EmpRE	5. How many of them work in the area of Reliability Engineering?	None	None
Q6.REuni	6. How many of the employees in Reliability Engineering have a university degree?	None	None
Q7.OwnRE	7. Does your site have its own Reliability Engineering department?	1	no
		2	yes
Q8.PlanRE	8. Is your organization planning to establish a separate Reliability Engineering department?	1	no
		2	yes
Q9.REtoDep	9. To which department does Reliability Engineering belong?	1	Maintenance
		2	Production
		3	Site Manager
		4	Engineering
		5	Others
		6	No affiliation
		7	Not yet determined
Q10.RErep	10. To whom does the Head of Reliability Engineering report?	1	General Manager
		2	Site Manager
		3	Production Manager
		4	Maintenance Manager
		5	Engineering Manager
		6	Others
Q11.MTCEstrat	11. Which maintenance strategy is pursued?	None	
A11.Rea	Answer 11: Reactive	0	not selected
		1	yes
A11.Prev	Answer 11: Preventive	0	not selected
		1	yes
A11.Pred	Answer 11: Predictive	0	not selected
		1	yes
A11.Text	Answer 11: Free text input	None	
Q12.REown	12. Can Reliability Engineering implement savings projects on its own, or does it need the approval of a manager (e.g. Asset Manager, Plant Manager, etc.)?	1	no
		2	partly
		3	yes
Q13.OwnPOV	13. From your experience, is this organization purposeful and reasonable?	1	no
		2	yes
Q14.REPOV	14. From your perspective, what should the Reliability Engineering organization look like?		None

Q15.REexcl	15. Do the employees in Reliability Engineering deal exclusively with plant improvement topics, or do they also take on other tasks?	1 no, also other topics
		2 yes, plant improvement only
Q16.REother	16. Which proportion of time is spent on other activities?	None
Q17.REmain	17. Which activities in Reliability Engineering do the employees in this area mainly perform?	None
A17.EvalMachData	Answer 17: Evaluation of data (e.g. SAP, machine data, etc.)	0 not selected
		1 yes
A17.CrStat	Answer 17: Creation of statistics	0 not selected
		1 yes
A17.MeasMachData	Answer 17: Measurement of machine data (e.g. temperature, vibration, etc.)	0 not selected
		1 yes
A17.HydMan	Answer 17: Hydrocarbon management	0 not selected
		1 yes
A17.FMEA	Answer 17: FMEA / RCA etc.	0 not selected
		1 yes
A17.FTR	Answer 17: First Time Right, mechanical instruction plans etc.	0 not selected
		1 yes
A17.ConPM	Answer 17: Consulting of the production management	0 not selected
		1 yes
A17.ConPS	Answer 17: Consulting of the production staff	0 not selected
		1 yes
A17.ConMM	Answer 17: Consulting of the maintenance management	0 not selected
		1 yes
A17.ConMS	Answer 17: Consulting of maintenance staff	0 not selected
		1 yes
A17.PM	Answer 17: Project Management (for plant improvements)	0 not selected
		1 yes
A17.Text	Answer 17: Free text input	None
Q18.REownBud	18. Does Reliability Engineering have its own budget for implementing improvement measures?	1 no
		2 partly
Q19.MTCEbudRE	19. What percentage of the maintenance budget is spent on reliability measures?	None
Q20.REcostRed	20. Has Reliability Engineering already contributed to a cost reduction at your site?	1 no
		2 partly
Q21.RedProdLoss	21. Reduction in production losses (in percent)?	None
A21.Expec2019	Answer 21: Expectation 2019	None
A21.Expec2020	Answer 21: Expectation 2020	None
A21.AcSav2019	Answer 21: Actual savings 2019	None
A21.AcSav2020	Answer 21: Actual savings 2020	None
Q22.RedMTCEcost	22. Reduction in maintenance costs (in percent)?	None
A22.Expec2019	Answer 22: Expectation 2019	None
A22.Expec2020	Answer 22: Expectation 2020	None
A22.AcSav2019	Answer 22: Actual Savings 2019	None
A22.AcSav2020	Answer 22: Actual Savings 2020	None
Q23.ExtOpTime	23. Extension of plant operating time (in percent)?	None
A23.Expec2019	Answer 23: Expectation 2019	None
A23.Expec2020	Answer 23: Expectation 2020	None
A23.AcSav2019	Answer 23: Actual Savings 2019	None
A23.AcSav2020	Answer 23: Actual Savings 2020	None
Q24.SavFuture	24. What potential savings do you or your organization expect in the future?	None
A24.RedProdLoss	Answer 24: Reduction in production losses (in percent)	None
A24.RedMTCEcost	Answer 24: Reduction in maintenance costs (in percent)	None
A24.ExtOpTime	Answer 24: Extension of plant operating time (in percent)	None
Q25.KPI	25. Which key performance indicators (KPIs) are used to assess the efficiency of Reliability Engineering in your company?	None

A25.MTCEcost	Answer 25: Maintenance costs	0 not selected
		1 yes
A25.ProdLoss	Answer 25: Production losses	0 not selected
		1 yes
A25.PIUpTime	Answer 25: Plant uptime	0 not selected
		1 yes
A25.Text	Answer 25: Free text input	None
Q26.REtarg	26. Does Reliability Engineering actually reach the given targets?	None
A26.MTCEcost	Answer 26: Maintenance costs	0 not selected
		1 yes
A26.ProdLoss	Answer 26: Production losses	0 not selected
		1 yes
A26.PIUpTime	Answer 26: Plant Uptime	0 not selected
		1 yes
A26.Text	Answer 26: Free text input	None

8.5 INTERVIEW CONSENT FORM MAIN STUDY



Interview Consent Form

Research Project Title: Organization of Reliability Engineering with focus on Cost-Efficiency

Research Investigator: Dipl.-Ing. (FH) Uwe Christian Bußmann MBA

Research Participants Name:

The interview will take max. 60 min. I do not anticipate any risks associated with your participation, but you have the right to stop the interview or withdraw from the research at any time.

Thank you for agreeing to be interviewed as part of the above research project. Ethical procedures for academic research require that interviewees explicitly agree to be interviewed and how the information contained in their interview will be used. This consent form is necessary for me to ensure that you understand the purpose of your involvement and that you agree to the conditions of your participation. Would you, therefore, read the information sheet and then sign this form to certify that you approve the following:

- The interview will be recorded, and a transcript will be produced,
- the transcript of the interview will be analyzed by Uwe Bussmann as research investigator,
- access to the non-anonymized interview transcript will be limited to Uwe Bussmann only,
- any summary interview content, or direct quotations from the interview, that are made available through academic publication or other academic outlets will be anonymized so that you cannot be identified, and care will be taken to ensure that other information in the interview that could identify yourself is not revealed,
- the actual recording will be kept until the end of the research process,
- if you are quoted directly, a made-up name (pseudonym) will be used,
- all or part of the content of your interview may be used in academic papers, articles, presentations, and, if applicable, other publications.



By signing this form, I agree that:

1. I am voluntarily taking part in this project. I understand that I do not have to take part, and I can stop the interview at any time;
2. The transcribed interview or extracts from it may be used as described above;
3. I have read this Information sheet;
4. I don't expect to receive any benefit or payment for my participation;
5. I have been able to ask any questions I might have, and I understand that I am free to contact the researcher with any questions I may have in the future.

Participants Signature

Date

Researchers Signature

Date

If you have any further questions or concerns about this study, please contact:

Uwe Bußmann
+49/(0)172/7534611
UweBussmann@gmx.de

8.6 INTERVIEW GUIDE MAIN STUDY



Interview Guide

1. Preliminary Remarks

This research is part of a dissertation of Universidad Católica San Antonio de Murcia (Spain) in cooperation with FOM Hochschule Essen (Germany) on the topic "Organization of Reliability Engineering with focus on Cost-Efficiency." This investigation is carried out as a so-called mixed methods study (quantitative → qualitative). The first step, a quantitative online survey, was already completed in spring 2021. The following qualitative expert interviews will be conducted in order to answer the research questions fully. Whether the participant has already taken an active part in the previous online survey is irrelevant for this expert survey.

The audio recording starts with the first question.

2. The Procedure of the Interview

The planned course of the interview (scope, duration, etc.) is explained to the person to be interviewed.

3. Language

The interview is to be conducted in English. If the interviewee prefers, the interview can also be conducted in German.

4. Interview Consent Form

The interview consent form is described to the expert to be interviewed. He or she has the opportunity to ask questions, especially about data protection. The interviewee and the interviewer countersign the form.

5. Questions

Note: The questions given here are used to structure the interview and compare the interviews. They can be modified or supplemented by further questions during the interview!

5.1 Basics/Organisation

- a) In which position do you work?
- b) → *If relevant: In which positions were you previously employed?*
- c) How long have you been concerned with the topic of "Reliability Engineering" and in what context?
- d) How is your maintenance organization structured and how is Reliability Engineering integrated there?
- e) → *If required for in-depth study: What should the maintenance organization look like from your point of view – especially with regard to the Reliability Engineering department?*

5.2 Reasons why companies want to implement a Reliability Engineering department

- f) Does your site/company already have a stand-alone Reliability Engineering department?



- g) ➔ *If no: Do you intend to introduce such a department soon?*
- h) ➔ *If no: Why not?*
- i) Why do you think more and more companies are introducing a stand-alone Reliability Engineering department?
- j) ➔ *If yes to question f) or g): Are these also the reasons why you already have or intend to introduce such a department?*
- k) Are these the only reasons, or are there any others?

5.3 Expected savings through the implementation of a Reliability Engineering department

- l) What types of improvements and savings do you expect from implementing a Reliability Engineering department?
- m) Can you quantify these expected improvements and savings (e.g., as a percentage to the maintenance budget or in actual totals)?
- n) Have these improvements/savings been achieved in the past?
- o) ➔ *If no: Can you say why not and in what time frame do you think the savings will be achieved?*

5.4 Evaluating the effectiveness of a Reliability Engineering department

- p) How do you track the efficiency of the Reliability Engineering department?
- q) Which Key Performance Indicators (KPIs) do you use?
- r) Are there any other aspects that you use to see or measure effectiveness? Please elaborate if this is applicable.

5.5 Achievable savings through a separate Reliability Engineering department compared to a conventional setup

- s) Taking all costs into account, what do you think are the particular advantages of a stand-alone Reliability Engineering department?

5.6 Concluding Remarks

- t) Would you like to add to or elaborate on any of the questions?

6. Closure and Farewell

The participant is given a farewell.

8.7 TRANSCRIPTED INTERVIEWS MAIN STUDY

8.7.1 Participant Information

Participant number	Job description	Country	Sector	Site size	Company size	Date	Duration [min]	Language
1	Reliability engineer	Germany	Chemical industry	large	large	07.12.2021	09:01	English
2	Reliability manager	Germany	Chemical industry	large	large	25.11.2021	15:14	English
3	Engineering manager	United Kingdom	Chemical industry	medium	large	03.12.2021	27:02	English
4	Area engineer	Germany	Chemical industry	large	large	26.11.2021	16:33	German
5	Maintenance manager	Finland	Energy industry	medium	large	29.11.2021	22:34	English
6	Works engineer	Italy	Chemical industry	medium	large	23.11.2021	57:14	English
7	Reliability engineer	United Kingdom	Chemical industry	medium	large	09.12.2021	44:54	English
8	Maintenance excellence specialist	United Kingdom	Food industry	large	large	02.12.2021	26:39	English
9	Reliability engineer	Germany	Chemical industry	large	large	08.12.2021	19:31	English
10	Production manager	Germany	Chemical industry	large	large	24.11.2021	19:53	English
11	Director maintenance & engineering	Germany	Chemical industry	large	large	23.11.2021	17:34	English
12	Reliability manager	Spain	Chemical industry	medium	large	09.12.2021	19:42	English
13	Head of engineering	United Kingdom	Food industry	large	large	06.12.2021	13:53	English
14	Mechanical maintenance manager	Germany	Rolling mill industry	large	large	14.12.2021	15:35	English
15	Maintenance manager	Germany	Aluminium milling industry	large	large	16.12.2021	16:48	English
16	Production manager	Germany	Building Materials industry	small	large	04.01.2022	20:49	English

8.7.2 Transcription Participant #1

Transcription

Participant No. 1

- Further information on the participant: See table in the appendix
- Date of recording: 07.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 09:01 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: So, the first question is: In which position do your work?

P: I work as a reliability engineer.

I: And in which position were you previously employed?

P: This is the first position after graduation.

I: Okay. And how long have you been concerned with the topic of reliability engineering, and in what context?

P: I've been involved for three years as a reliability engineer.

I: So, and how is your maintenance organization structured, and how is reliability engineering integrated there?

P: We have a centrally organized maintenance department and reliability department. We have our own reliability department there.

I: And, so, but the whole main structure, so can you tell me something more about the maintenance in general.

P: We have a site with five Betriebe (production areas). We have a centrally organized maintenance department, which works for every of the five Betriebe (production

areas), and, yes, we have a pump workshop, and we have a Konti, and we have our own engineering, and at this engineering, we have a reliability department.

I: Okay, thank you. So, as I understood, your company already has a stand-alone reliability department?

P: Yes, yes.

I: And not talking about your company, but on companies, or companies in general. Why do you think more and more companies are introducing a stand-alone reliability engineering department?

P: I think that you can, wait a minute, I think if a company sees that an own reliability department is very effective to reduce maintenance costs and production losses. So they implement their own department for this context.

I: And, well, are these the same reasons why you, on your site, have already such a department?

P: Wait a minute (...), I don't think that there are any other reasons. But, what/ question K, yes?

I: Well, question J and K, yeah.

P: J and K, yes, I think these are the reasons why we introduced our own readability department at our site. Because our company at successfully tested it at our site.

I: Perfect. The next question is about expected saving through a reliability department. So, what types of improvement and savings do you expect from implementing a reliability engineering department?

P: I expect higher system availability, lower maintenance costs, and less production losses.

I: And can you quantify these expected improvements and saving? So, for example, as in percentage of maintenance budget or whatever?

P: I think we can. It's about five percent of our maintenance costs.

I: Okay and, well, and the next question will be: Have these improvements or savings been achieved in the past? But you already said yes, they have.

P: Yes.

I: It's perfect. The next block of questions is about the evaluation of the effectiveness of the reliability engineering department. And here the first question is: How do you track the efficiency of the reliability engineering department?

P: We have KPIs, and with these KPIs, we can check if we could reduce maintenance costs. For example, if we can (...) create a higher system availability.

I: And you are already tracking that you take those KPIs on a, whatever, weekly basis or whatever?

P: Yes, we take these KPIs and create them by ourselves.

I: So, are there other aspects that you can see the effectiveness of reliability engineering on, for example, in reduction of production losses or something like that?

P: We have a loss accounting. This loss accounting comes from the Betriebe (production areas). With this loss accounting, we can check if we lost much product of maintenance, because of maintenance works or not. And if we had a reliability project on, in case of that. We check if the production losses are the same in the next year, or if we could reduce them by our projects.

I: And do you use mean time between failure or other OEE KPIs?

P: Yes, we also used mean time between failure. We check from the analysis of our SAP data. We look at how much maintenance works we had in the year, how high our costs are in a year, and we check these KPIs after a year or two or three years after a project. So we can see if the project was effective.

I: Very well, so, if you take all those costs into account, what do you think are the particular advantages of a stand-alone reliability engineering department?

P: I think a separate reliability department can better focus on resources, and therefore it works more effectively.

I: And coming to the last question: Would you like to add or elaborate on any of those questions?

P: No, I think that gives a good overview of our work and the organization we have.

I: Okay, and thank you very much.

8.7.3 Transcription Participant #2

Transcription

Participant No. 2

- Further information on the participant: See table in the appendix
- Date of recording: 25.11.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 15:14 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: So, first question: In which position do your work?

P: Actually, I am the team leader of the reliability engineering and the self-monitoring department. Yes, for two months.

I: Okay, what did you do before?

P: Before that, I was, for nearly three and a half years, employed as a reliability engineer.

I: Okay, on the same site?

P: On the same site, right!

I: And in general, how long have you been concerned with the topic of reliability engineering in that context?

P: So in my actual position, it's nearly four years, but I already had contact with the reliability engineering before, more or less. It wasn't one named like that, but I was working in several industries and always had to do, had to deal with maintenance and all those things that are mostly called reliability right now. So talking about condition monitoring tools or something like maintenance plans or checking machinery via routes. This is all kind of reliability right now, and before, I already had something to deal with it.

I: Okay, thank you. So how is your maintenance organization structured, and how is reliability engineering integrated there?

P: The maintenance in our company is mainly separated into different departments. Like, we have got project engineering, we have got, the workshops, we have got electrical and mechanical sides. Although we have asset management teams and as a department on its own the reliability engineering.

I: And from your personal point of view, what should the maintenance organization look like? Especially with regard to reliability engineering?

P: I think the way we keep it, it's the right way. Because reliability is really important, and I think it's mainly important, that it's a department on its own. Because the work that we are doing is interfacing with all the other departments. We are trying to overlap our work with the other departments and try to support them. And I think that's the main point, why it should be independent.

I: So, the next question will be: Does your site have already a stand-alone reliability department? But you already answered that. You do have such a department.

P: Yes, we have that.

I: So, the next question is: Why do you think more and more companies are introducing a stand-alone reliability department? Not thinking about your company, on companies in general.

P: Companies in general, I think it's that's mainly the technology is raising, and it's getting more and more important to use new technology. All the companies need to reduce the costs and try to be competitive on the market, that's mainly the reason why they also need to reduce their employees. And that's the most point where reliability can lead and can support because we can implement new technology that helps us to implement new maintenance strategies and to get the know-how that normally the craftsmen had. So, like, in the past, it was many that there was, let's say, a metalworker works in the workshop, and he knew what to do. And when he passed a machine, he could use his sense to understand what's going wrong with the machine. Right now, we don't have this knowledge anymore if those people are leaving the company. So, we need to find technology to save this know-how. We need some new ways to analyze the machines, to find the life cycle and, yes, I think maybe that's why most of the companies are going to implement such a department. Although I think that you need one department that's dealing with the problem and that's leading and supporting it because otherwise, every own department would have their own systems. In the end, they all are cooking their own soup, like everything is different.

I: Okay, thank you. Are these the same reason why you already have started such a department on your site?

P: Yes, many the reason was to reduce costs in maintenance and increase the production. At least the technology implementing is following out of it, so. I think the main point that they try to implement such a reliability department was to reduce cost. Just to be competitive again.

I: Are these the only reasons, or are there any other reasons as well.

P: Well, I think, as I said before. Reducing cost always means that you need to improve your process, and if you are implementing new technologies, you can improve your process, and you can reduce costs. But although you can increase production and as a result that like, yes, that's leading out of it, it's so you've got a lot of reasons to know your assets to know how your production works and how to improve maintenance strategy.

I: Okay, thank you. So, the next block of questions is about the expected savings through a reliability engineering department. So, what types of improvements and savings do you expect from implementing a reliability engineering department?

P: I think the main improvements are that you can reduce costs. You can get the knowledge of your assets, you can lead into predictive maintenance, preventive maintenance. You can use a modern maintenance strategy, and also you can improve the safety performance because this is also a point that goes with it. And you can extend the lifetime cycle of the machinery, of the assets, that's really a big point. Although you can reduce issues with your machinery, you can find savings in production, even if you've got to reduce your employees. Yes, I think that's the main benefits are that you can reduce costs, that you can save production, save your safety performance and improve technology.

P: Can you quantify those expected improvements and savings, for example? So, in percentage of reduction in maintenance budget or in percentage of increased production?

P: Yes. So, it's hard to say in general, but I would say regarding to the budget that we have, it will be about four percent of it, that you can improve and can find savings/

I: Per year?

P: regarding to the budget/

I: Four percent per year?

P: Yes, per year of the budget, yes. And, regarding production increasing, I would say, there is even more room and more saving that can be done. But this is mainly regarding what kind of issues do you have. Sometimes in a year, it might be a really big loss accounting, and you've got like one machinery that got issues, and you can really get

a big amount of production increase if you repair the machine, the right way. And the next year you might have a lot of little things, little issues and then it's quite harder to increase the production.

I: And have these improvements or savings been achieved in the past at your site?

P: Yes, I would say we achieved a lot of good things in the last three years. So, in general, we've got critical equipment that we could push up to the limit and to a saver functional service. We also could realize that by tracking that machinery, tracking the work orders, and the loss accounting, that there is a change that the machinery, that once was really bad, are going to be a good one right now. And I think that's the main point where you can see it. If you track your work orders and if you track the costs of work orders, you can see how it changed.

P: So, the next block of questions is about evaluating the effectiveness of a reliability engineering department. So, first question here is: How do you track the efficiency of the reliability engineering department?

I: As I said before, it's like we are doing a bad actors analyzes, and so we are trying to track the critical equipment and try to understand if the work orders are going up or down, try to understand how much do we pay for the repairs. So, in this way, we could track how does our improvement, how does it change on the whole site. Furthermore, we try to collect all the improvements at the end of the year and count them together like in a calculation with savings and production increasing and try to report it like this. But mainly we use saving and the number of work orders. Yes, but in general, I would say that's the best way to show how it works in reliability engineering.

I: And these are the KPIs you use?

P: These are the KPIs that we are using.

I: Are there any other aspects that you use to measure the effectiveness of the reliability engineering department? Despite KPIs that means?

P: Yes, I think another measurement is the acceptance inside the site. Like if you're going to a craftsman or to an operator, you get a feeling of how you accepted, and more and more, they realized that we are there to support and to help. And I think that's really a big point that's giving the reliability engineering some pushing, some atmosphere that is added to the department. And I think that's a big point when you can see if you're on the right way when people come to you and say we've got a problem, can you help us?

I: Thank you. So, coming almost to the end. If you take all the costs into account, what do you think are the particular advantages of a stand-alone reliability engineering department?

P: I think the main advantage is that you can focus on a modern maintenance strategy. That you can go with the time take new technology, implement them, try to save your production and try to save your site by the using them. And even if you have to reduce employees or have to reduce anything that might be influencing your production. You can find a way to monitor your machine and to collect work in one place where you can lead and support to the system. So, I think it's always a big point to know about your machinery and the main point. If you know what's going on in your machines and in your assets, you will find a way to solve problems.

I: So, the last question is: Would you like to add or elaborate on any of these questions?

P: No, I think these are quite good questions, and they lead to another. So, from my side, I wouldn't add anything.

I: Okay, so, thank you.

8.7.4 Transcription Participant #3

Transcription

Participant No. 3

- Further information on the participant: See table in the appendix
- Date of recording: 03.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 27:02 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: So, in which position do your work?

P: So, I'm currently the site engineering management manager at (site).

I: And in which position did you work before?

P: Before, I was the global engineering leader.

I: And how long have you been concerned with the topic of reliability engineering, and in what context?

P: Do you mean at this site, or do you mean in my career?

I: Well, in general.

P: So, in general, I've been involved in reliability engineering, probably (...) twenty years, twenty years involved in reliability engineering, on operating assets. Twenty years of working operating assets on chemical sites.

I: And

P: on various

I: Yeah, go ahead, go ahead if you want to add something, perfect.

P: So, yeah, and in that twenty years, I've probably been engineering manager for most of that, for probably 15 years. I was engineering manager with direct responsibility for a reliability function within my team.

I: And how is your maintenance organization structured, and how is reliability engineering integrated there?

P: So, the way we are moving forward here, in the future, so currently we have a central reliability engineer which is (name), you know. (name) tends to focus on rotating equipment reliability and not other equipment. But then, in the assets, we have an ICON production facility which has technical engineers who have a responsibility for reliability in the white end, which is the same as your white end. We have technical engineers again who have responsibility for the reliability, but reliability is only part of their job is not their full job. Going forward, we are making some changes to the organization so that strengthening the reliability group.

I: So you now, just explained how it looks like at the moment. And from your point of view, what do you think it should look like if you could change it?

P: So, going forward, we will have a member of the central engineering team who will be, let's call it, the reliability manager, so he'll be responsible for managing reliability. But that is managing reliability across all the assets. So, he will have a reliability engineer who is responsible for the ICON plant, which is like your Schwarz-Mittelbetrieb (black end). And you have an asset engineer, reliability engineer who will be based in the Weißbetrieb, in the white. Who is responsible for the white end. So, we also structure reliability. So, it's what I call a triangle approach so that you will have on each of the points, so you have technical reliability in the assets who focus on engineering-type solutions. Reliability effect is on maintenance routines. Production will have a point part to play in that. So, they're looking at startup shutdown routines and how they improve operation, operation reliability assets. And then there will be central engineering. That will look at long-term reliable issues. So, the asset will focus on short-term reliability issues in production and maintenance. And then maintenance has to play its part as well. So, maintenance, engineering, production is the three-point triangle. Does that make sense (name)?

I: Absolutely. And so, that means you, a moment, you do have a stand-alone reliability engineering department on-site?

P: Yes, we have a guy. We have (name). Yes, we have, essentially, we have a central reliability engineer who looks after rotating reliability. And then, in each of the plants, we have technical engineers who have a part of their job is reliability, but they don't tend to focus on reliability. They get sucked into the day-to-day maintenance breakdowns. Get it fixed, get it fixed, get it fixed, rather than what do we need to do to stop this breaking down in the future. The focus on, you know, they'll have six

breakdowns to the same piece of equipment, but not actually address the issues. And not doing records that look at long-term improvements, that make sense?

I: Yeah, so now talking about companies in general, so, not your company.

P: Yeah.

I: Why do you think more and more companies are introducing a stand-alone reliability engineering department?

P: Why they did/ I think because, historically, reliability has been a part of an engineering function, whereby the engineer, on a site, might be doing project, he might be to breakdowns, he might be managing upgrades and overhauls. And reliability is part of his job. And what happens is, they tend to become focused on production. Get more tons, more tons, more tons, get it fixed. They become heavily focused on keeping equipment online as long as possible, making as many tons. And they start to spiral then. The equipment condition starts to deteriorate. But the way it deteriorates on more complex equipment is, you don't see an immediate failure, you see a gradual deterioration in the function and that, you know, something starts to sort of fail. And you correct it, but you only corrected to a little bit of a percent. And then deteriorates again and you correct a little bit. And then if you look over time, actually you are a long way from the original 100 percent as build, as designed function. You got a piece of equipment now, it's running, but it's doing only eighty percent of the rate that it should be doing. And it keeps addressing. So, I think companies are going more for focus reliability groups, who can focus on these long-term issues rather than short-term issues. So it's about making sure you're doing long-term, you're doing the routine, you're improving the routines, you're improving reliability, you're upgrading equipment, you're talking to them. Another big area, talking to manufacturers. We found here that, I have seen in other/ many company companies, you have a piece of equipment, let's say like a filter press, and you just focus on production through that filter press and keeping it running. But it's slowly deteriorated, the filter press, you know, and then periodically, you spend a lot of money on bringing back up to some sort of standard. What you never do is look at actually, is filter press the right way? Should we be changing the cloth material, should be upgrading this, upgrading that, and you know, talking to the manufacturer is the OEM's we say. Original equipment manufacturers, OEM's. So, talking to the OEM's about, you know, can it be upgraded, is there a new technology, is a new way of doing things, were different types of valves, we can use. And you don't get that unless you have stand-alone reliability functions that are really focused on the long-term. And something I always say, everywhere it goes, is when you have reliability people based in the assets, there are very focus on keep the plant running. And when the plant breaks down, it's about whatever quick fix you need to do to get back online. That quick fix is not always the right thing to do. You know this (name). But what they also tend to do is, they start doing some proactive reliability. But what they're doing is they're looking at loss accounting, OEE data,

looking at what happened, looking back, in the, they driving the car, but they looking in the rearview mirror. They are looking at what happened. And is an element of reliability is. Yes, you go, look at the review mirror, because that is sorting out the problems of hurt you recently and gonna hurt you again. You've got to look out front screen to see the reliability problems coming down the line. So, you know, we, and I have seen in many sites will put a new piece of equipment in, new filter press or a new this. And we don't focus on the reliability that until it's in the rearview mirror. So, ten years later in the review mirror because it's breaking down this problem's, blah, blah, blah, blah, blah. But if you be focused on, you know, from day one looking out the front of the car, then you might have been tackling some of the issues. We have this here we got some programs we're going where we're tackling the loss accounting problems. The rearview mirror. What we are not doing is looking forward. What is the critical asset out there? It is no problem now but will be a problem in the future if we don't sort out the maintenance, the routines, the focus on it. Does that make sense?

I: Absolutely! Are that the same reasons why you have reliability engineering on your site, or any other reasons for that?

P: I think that is the reason why we/ that's one reason why doing this, but the other reason is if you look historically, sites have gone through cycles of, you know, of, in the '70s that the market went down in 2008 the world economy, economies of the world. So, the world economy goes through cycles, and we had, you know, some big, big dips. In the '70s, 2008, COVID has caused a big dip. What tends to happen is, sites tend to, they cut the workforce, but the workforce they cut is not the production workforce because they need those guys. They tend to cut the people they see as not essential and usually is the reliability people. So, you have worked on sites where reliability people have when they've been cutting the workforce, reliability people are some of the first people to get rid of. Because they can't afford to have the reliability people who just chance it will run. So, then they end up with a large site like (site) site where is only one reliability engineer, or there was only one reliability engineer.

I: Yes.

P: Now, I don't know the history, but I bet it was more reliability engineers on (site). At some point, somebody said we need to cut our numbers. What will we going to cut? Get rid of some of the reliability engineers. So, that's another reason that going I think, some companies now bringing reliably, is coming back to the forefront as the economy picks up. I need to do more production, the plants is not reliable, because we are not be spending any money. So, they're in the cycle, decide the plant, the world economic cycle of the plant, on the plant they need more reliability that got more reliability people because they all gone. So, they start recruiting, and then you see this, oh, we've got a new reliability department. It's just a cycle that they gone through the realize that reliability is important again. We are going to that now as (company) because we can sell every, all material we can make we can sell. So, reliability has

become quite important. When the economy goes into a downturn again, then costs and headcount become important. So, sometimes this reliability thing depends on where the economy is or whereas a company you are in your, you know if you're a growing company where you're growing all the time that great. If you're a cyclic economy or cycling economy or cyclic business, like PETG, the plastics industry, it's quite cyclic. So, you know, reliability teams go out the door when the economy is going down, and they come back in the door when the economy is going up. Does that make sense?

I: Absolutely. So

P: I saw that at (site), so you were the only reliability engineer in (site), when I went there.

I: True.

P: And now you got now three or four. I can't remember how many now you go. Three, probably, and part of that was because (...) headcount cut, cost cut, no market for the material or less market. Get rid of people. And then when I was there, it started to pick up the market, didn't they? And it was all about getting more production. Get more, so, you know, then we got have the conversation with (name) and say, well, if you want more production, then you need more people. At (site), the stimulus for bringing (name) and (name) in, the big opportunity was when we had that, there was a screw feed, or something failed. And it costs us a lot of money. It was something like three-quarters of a million euros or something. It was big, it was a big number, it was a big number, and that focused the minds. And (name) said to me, how many reliability engineers do I need (name)? I said you need at least one, at least one for every plant. And that's when she said we can have two. And that's when we recruiting (name) do you remember?

I: Yeah, I do.

P: That's when we got the okay. It was the opportunity to, but again, it was on the back of, the economy is picking up, we need more material, the market is there, the plant is unreliable. So, I think, you know, that cycle does have an impact on the reliability functions they come and go based on the cycle.

I: Okay, what types of improvements and savings to expect from implementing reliability engineering department?

P: Oh, wow, that's a good point. We expect to make, I give, I'll tell you the number.

I: Yeah, the next question will be: Can you quantify these expected savings?

P: Yeah, I can, yeah I can (...) you can't see screen, can you? See what I'm up to, so.

I: But you're aware that I don't have the screen on my audio recording, right?

P: Yeah, I know that, I'm going to tell you the numbers. (...) you are cruel, you're a cruel person, you writ/ because I'm English doesn't mean I'm completely stupid. Finished. I'm going to find the numbers for you. (site) capacity improvement project.

I: But if you give a rough estimation, that would be fine.

P: Yeah, yeah, (...) it's on the first. Where is it? Oh, go away. (...) See, (name) hasn't got the numbers because he's not being involved, so (...) so, I'm looking where the number is hidden in all this lot somewhere. Einen Moment (One moment) (name) (...) so, this is progress slides, this is the kick-off meeting, it might be on here (...) no chance on that. This is annual. I know you can't, so our base is/ So these items here, primary (unintelligible, indistinct) filter, all the team reliability projects to the team are focusing on. So, in the short-term, we're looking at improving from eleven, reduced now losses from, I don't know what it is, let's say seventeen down to an eleven. So let's say 6,000, we're helping to achieve 6,000 tons of savings.

I: In production losses?

P: In production losses, yeah.

I: That's one of those things in a reduction in production losses?

P: And that production loss would amount to 7,000, how to say 7,000. I don't know, we sell it for, what the number is, two, three times say what do we sell for 3,000 euros a tonne, you know that? So that's, fuck you know, it's 21,000,000 euros the value of that material, that's what we are looking for a saving.

I: But are there any other things, like reduction in, well, maintenance budget or anything like that? Do you expect those?

P: Yeah, I mean, we haven't got a number on it. We're hoping to get a reduction in the maintenance budget and increasing uptime. You know, (...) there will be if we can run the plant steady, there are some production savings in terms of variable cost savings. Because, if we run steady, then we use less energy with use raw material we if you run steady, we don't choke the plan as often so that there is variable material costs. But there are also production costs, as in we can reduce the (unintelligible, indistinct) clean. Shutdowns for cleaning, lah lah lah, you can save on the number of shutdowns. Have shorter shutdowns. We have a more reliable plant, so we're not going to do major overhauls and major repairs. So we, it is a number of opportunities variable cost, direct maintenance costs, variable production material costs, uptime and actually this lost ton of 7,000 tons, it looks like 7,000 tons, which is, wow, I don't know, 21,000,000 euros.

I: Have you actually achieved those expected savings? You said for the production of course, but all the other things you expected to save?

P: Well, we actually drove it more. So, if you, look, I know you can see the graph and your voice, but you can seem to (unintelligible, indistinct). We drove it down as low as five, so from our baseline, we went from sort of seventeen down to five. So, we made eleven kilotons a year improvement. Unfortunately, we have some reoccurring reliability problems and brought it back up again. So, if you take it, simply start from the project we dropped from say seventeen, actually looks like seventeen and a half we've dropped down to fifteen. So, we've saved, so, two and a half thousand tons of lost production saved in the last six months. Two and a half thousand tons at 3,000 euros.

I: So, and do you track the efficiency of reliability engineering? For example, special KPIs or something like that. Do you have special KPIs for reliability?

P: We don't have special KPIs for reliability, but we have, we measure OEE. We use OEE as a measurement what has an element in it. Why do loss accounting, so we will measure lost tons for, due to equipment failures. We also monitor online time, which can be, you know, that's part of OEE. Then this on the graph I share to you (name) is, were monitoring so for the pieces of the one, two, three, four, five, six, seven, eight, nine pieces reliability equipment on that graph. We are monitoring specifically monitoring them to see are projects we're doing improving our loss accounting. So, we're doing a cumulative loss accounting for the target areas. And what will do is probably in the new year, we will revisit all the loss accounting, all the OEE. Will identify the next tranche of reliability projects and then will monitor the loss accounting for their areas. Trying to drive them down as well. Is rather just doing a project and say, wow, doing a project is great. We are monitoring how's that project, how's that reliability improvement project being successful. And you can see on this graph that actually have to be very successful until September and then there more problems with the (unintelligible, indistinct) cooler.

I: So, are there any other aspects you can use to see the effectiveness, like less work orders for contractors or something like that? Do you monitor other things as well?

P: We're not really, no, not really monitoring that. I guess the other one we monitor on a corporate level. We do look at maintenance budgets as an assentitive asset replacement value. So, we're looking to achieve a number, somewhere, sort of that between three and four percent of your maintenance costs of percent of your asset replacement value. The idea is that if you got a reliable, well-maintained plant, you should be able to get out to three or four percent. Very much depend on the industry were using a number of three or four percent. If you go into other industries like petrochemical, where there it's less erosion, less corrosion type issues, then you probably a world-class number of 2.5 percent of its asset replacement value will be

really good. There's another way of, you know, if an investor was coming to buy your plant, he will probably look at that number and say, yeah. And if it was, you know, if you, if you're percent of asset repl/ if your maintenance costs a bit of the asset replacement value and it was ten percent. He will be thinking is not a very good plant, not very reliable, you know, you spent far too much on maintenance. So, your maintenances costs can be used as a way of inferring reliability.

I: So, now, if you take all those costs for a reliability engineering department into account, what do you think are the particular advantages of a stand-alone reliability engineering department?

P: (...) Well, the particular advantages are that there are focused, there focused on reliability, they not getting, they not getting distracted by can see this on, they are not getting distracted by other activities, they are focused on reliability there also, as I said, they're not just looking in the rearview mirror. They are anticipating future reliability issues. They can also get involved in projects. And some look at inherent reliability in equipment. When you install new equipment, do we install two, do we install one, or which manufacturer. They can start looking at whole life costs on projects, rather than the project team just buying the cheapest equipment. That's focused on that. Again, that's looking forward, so as always, forward-looking stuff they can do if we have a stand-alone reliability team. You know, what's going over, horizon, life cycle costs, obsolescence is another area that they can start focusing on. We tend to just focus on obsolescence. When a manufacturer says to us, we don't supply them anymore, we panic. Where they could focus on obsolescence is part of reliability as well. They can, yeah, focus on this OEM, working with the OEMs to improve the equipment. What else can they do? Yes, I think that's it. Was that question, does that answer that's the question?

I: Yeah, that's perfect. So, we coming to the last question. So, would you like to add or elaborate

P: Oh, sorry, they can also focus on technology. Condition-based maintenance technology. There is so much they can do, but new technologies around, you know, vibration monitoring, condition monitoring, acoustic monitoring that should be a part of their focus as well. Looking at what technology is in the marketplace and what can we bring to start improving our reliability and predicting equipment condition and forecasting failures, and that.

I: Okay, so would you like to add or elaborate on any of those questions?

P: No.

I: Okay, then thank you very much.

8.7.5 Transcription Participant #4 (English Translation)

Transcription

Participant No. 4

- Further information on the participant: See table in the appendix
- Date of recording: 26.11.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Translated by: Uwe Christian Bußmann
- Duration: 16:33 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in German and then translated into English. The interviewer is a native German speaker. The participant is not a native German speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: And the first question is: In which position are you now working in the company?

P: Now I am working as an area engineer titanium one in the black end.

I: Okay, and what positions did you have before in the company?

P: Before that, I was also an asset and reliability manager, so I was responsible for the operations and area engineers and the reliability engineers. But there was a reorganization last year, since then area engineer titanium one.

I: Thank you, how long have you been concerned with the topic of reliability engineering, and in what context?

P: We have been concerned with reliability since 2015, and I have been in maintenance since 2008.

I: And in all that time, you have also worked with reliability topics, permanently?

P: Exactly!

I: Can you, I have to say, briefly maybe try to explain how maintenance is structured at your site? So, who reports to whom and so on, and how reliability engineering is integrated into the maintenance organization?

P: Now I can say that because, in the past, it was a bit different here. With the current reorganization, it's structured in such a way that each area engineer - we have three areas - areas: titanium one, two, three, and each area engineer reports to (name), that is, to the maintenance manager, so to speak. We report to him, and he reports to the site manager (name). Each area engineer has about, circa, nine to ten mechanics, a subcontractor coordinator, a foreman, and a master craftsman under him. Plus, each area engineer has an operations engineer, so two engineers per area work off all the actions and the try, the tasks, for example, day-to-day operations. Also, the more general tasks such as reliability, PSM, SAP, writing work instructions. They also do that along the way.

I: But you also have your own reliability engineers who do nothing but reliability, don't you?

P: No, we do not have that.

I: Okay, so that's integrated into the actual maintenance?

P: Exactly! Every area engineer and operations engineer, on the site, so to speak, does a little bit of reliability as well. But after the reorganization last year, because we had very few engineers in our company, the reliability department no longer exists. It has no longer existed since January.

I: And now you have explained how it looks, currently. But from your point of view, you can, of course, say, that is okay for me now, how would you imagine a maintenance department at your site should look, and how would the reliability engineering be integrated there.

P: So now, how it is structured. It is very, very good because the area engineer and the operations engineer can focus on their responsible areas. That is not anymore, for example, before a year ago. The whole five years for the reliability and asset manager took care of the whole plant. But now we have done it in such a way that we almost have the old structures back, and each area engineer takes care of his own area and the standard that we built up before. That the area engineers, for example, all three work together again, so that the standard and the harmony, for example, is maintained, we have meetings every Friday, which standard, for example, we still follow and everything. That we work in a consistent way, that works very well, and I really wish we had a separate reliability engineering department here. So, in addition to this structure, another department that just takes care of optimization and improvement, I would have liked to have something like that here.

I: We will come back to that in a moment. The next question is: Does your site have an independent Reliability Engineering department? You have already answered that: You had it until recently, and now you do not have it anymore for a few months.

P: We no longer have it for a year.

I: Are you planning to do something like that again...

P: In the last five years, that was a very, very small department with two reliability engineers, one of them was a technician. One had been an engineer, and myself along with that. So, we were actually in the Reliability department the whole four, five years only one and a half men. Actually.

I: Are you planning to introduce one again, an independent department? I understand no because you just changed that recently. You do not want to go back to that. It will stay like that.

P: It will stay like that, yes. The reorganization has taken place, and it will stay like that for now.

I: Is that for cost reasons, or why did you do it that way?

P: Because we are not allowed or able to increase staff.

I: Okay, if you do not think about your site and your company, but more generally about other companies, in the last ten years, more and more companies have introduced independent reliability engineering departments. Why do you think that is? Why are more and more companies introducing such a standalone department?

P: Because, I think, many have seen through reliability, reliability also means plant availability and optimization. And through this, one actually achieves a great deal, for example, with operating plants, that the reliability, that is, diverse inspections, servicing, how they are repaired, optimized repair or also process-technically and mechanically, that one finds an optimal value so that the life cycle of the entire plant is actually much, much better than before. Just running through that does not do anything. That means good inspection, optimal process engineering, brings a lot. I think they understood that.

I: Are these also the reasons why you introduced a reliability department at your site in the past? You said in 2015.

P: One of the reasons has been that and we also have within those four, five years, for example, also done studies, then we have changed and optimized the maintenance schedules, we have changed inspection schedules. That is what we have carried out. So, with the one and a half man that we had actually and we took care of problems after we did all the SAP evaluations or daily business evaluations. Did we see some problems and with the department we then tried to achieve the optimal state, actually.

I: The next block of questions is about the possible savings and improvements through such a reliability engineering department, and the first question is: What kind of improvements and savings do you actually expect from a reliability engineering department? A couple of things you had already just said.

P: Exactly. If I list them briefly, they are: optimized process engineering. Through optimization, you then have less use of mechanics, less use of operations in the event of problems. Then we also have better optimization in maintenance thorough inspection and maintenance. Then the life cycles of the existing equipment are then extended the equipment availability. This also increases the whole production, and with that, you also lower the whole costs, actually. If I extend the life cycle, I actually increase the preservation of the plant, reduce the whole costs, and as I said, through the studies, I also get a standard spare parts stock in the warehouse. This means that I have to store less in the warehouse, if I may say so, but I can plan for the long term.

I: Can you somehow put these savings, these improvements that you have just mentioned, into figures so that you can say, for example, that we have been able to save two percent in maintenance costs through the use of reliability engineering? Something like that? Do you have anything there?

P: Yes, we did, and I can give you a clear example. We had a lot of pump costs, we had within of these four, five years, and through our, we focused on all the costs, and repairs on the pumps, for example, and within the three, four years we went from 1.9 million euros per year, across all areas, we came down to 1.1 million euros, including new pumps that we ordered, for example.

I: So, you have really made significant cost savings at this point.

P: We have saved costs, yes.

I: Yes, okay, great. The next question would be, how do you measure the effectiveness of a reliability engineering department? You have just said that you have looked at the costs and have saved costs. But are there may be other, for example, key performance indicators or something like this where you can see if reliability is working the way you want it to work? Have you tracked any KPIs?

P: Yes, our biggest KPI indeed has been our costs. That was one of the KPIs.

I: Maintenance costs? Sorry, maintenance costs?

P: Maintenance cost. We're just talking about maintenance because our reliability team, at that time also, was just taking care of maintenance. Well sure, in combination with production together, but there were only maintenance people working in our group. One of the KPIs was our costs, then one of the KPIs was the maintenance plans, that is, how many maintenance plans do I have in the year, in the month, and which of them have I worked off, for example, in our weekly planning, monthly planning, annual planning. Then we also, one of the KPIs had been. At these problem points, for example, with the SAP, one could determine the frequency of the disturbances at an equipment part and KPI had been then, which equipment part has for example, whether it gets every week a disturbance, every month a disturbance gets. We looked at the frequency of the problems and therefore also approached this problem with our team. And then we discussed everything with the production department. One of the KPI's was also that the agreement with the manufacturing management, plant area managers, site manager, that the previously known problems such as the mill, such as the furnace itself, such as the entire filter equipment, that one has a study for this, which has applied all these fishbone problems and this fishbone methodology, for example. These studies are then completed, and the result is the procurement of spare parts, which malfunction is there, which equipment parts do I need, the critical equipment parts, the safety-critical equipment parts are defined, and the results are then available. We have done this for some areas, and, as I said, after the restructuring, each area engineer continues to do things for himself.

I: Now, there are perhaps other aspects besides KPIs, as you can see that reliability engineering works. Are there also other things in your company? For example, that production losses have declined, something like that?

P: Yes, there is. Production losses are also looked up. For example, if you have, we had the case last year, a critical pump. It was defective due to the production, which did not flush the pipes, for example. And there we have changed four pumps within two, three days and at the that was on the weekend, and on Monday we looked in, the pipeline, been full of clods, and that has clogged again and again, and when pressing with the pump, we have seen that the pressure comes on the rotating mechanical seal and the pressure is built up and has then busted, become defective. And find such things, then you find then in the production loss chart, you find something like that. And then you also look, later, and so that this case does not occur, that you always follow these things also. These kinds of. Defects.

I: If you now consider all the costs that such reliability engineering generates. And you have had one for several years. What do you think are the most significant advantages when you look at independent reliability engineering from your point of view?

P: From my perspective, you really increase plant availability and cost savings across all areas in maintenance itself. And, to be honest, I would like to see, for example, that with our four men, we have it so that the reliability teams take place in maintenance, would actually be excellent, if this were a combination with production, that the process engineering including the mechanics, for example, is optimized by working out the spare parts with the plant conditions with the parameters in production together, for example, in cooperation. Which optimal criteria can I reach with my reliability, then still good efficient aims would be able to reach, I say.

I: Yes, then we come to the end of the interview, so to speak. Now you have the opportunity again: Is there anything else you would like to add or elaborate on the previous questions?

P: No, as I said, my aim would be, actually or my wish would be a reliability team between production and maintenance together, because, then you don't come up against, yes, barricades or barriers, which are then immediately lifted between production, and maintenance, if a joint team would work, actually.

I: Okay, then thank you very much!

8.7.6 Transcription Participant #5

Transcription

Participant No. 5

- Further information on the participant: See table in the appendix
- Date of recording: 29.11.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 22:34 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: And the first question is: In which position do your work?

P: Currently, I work as a maintenance engineer in (company).

I: And

P: and

I: Go ahead, go ahead.

P: Maybe, something from my previous company, so history. So, if we go back in the timeline. From the current position, so, maybe next week, this week, actually, comes the whole year in the current company. Before that, I work as a continuous improvement manager in the Middle East area, in the middle east market area. And was responsible for the continuous improvement of the service of this (company) company which is basically building minerals and mining processing equipment and also responsible for the services on that equipment. And before, that took about two years in that position, and before that, about three years in (company) company. I worked as a reliability manager, responsible for a team of five technicians, reliability technicians, and then one supervisor, one preventive maintenance team's supervisor, and he had a team of eleven mechanical or preventive maintenance technicians or mechanics in his team. And some reliability experience before that, I worked for about ten years for (company) as a reliability consultant. Did a lot of improvement projects with different industries within Finland and a little bit within the neighboring countries as well. And basically, my reliability-related interest and career started with

my master's thesis for this paper mill. I think the subject was to study with those studies (unintelligible, indistinct) reliability with the fault tree analysis and that got me started the reliability, reliability area.

I: Interesting, thank you. Can you, well, explain, maybe for your job as a reliability manager, how's the maintenance organization was structured, the whole maintenance organization, and how is relative reliability engineering integrated there. So, who reports to whom? So, the reliability engineer reports of the reliability manager, the reliability manager report to whom, and stuff like that.

P: Alright, about that, already mentioned, under my responsibility were five technicians and the preventive maintenance mechanics team. Those were separated from the day-to-day maintenance from like, even though they, of course, the mechanics did some corporation and so on with the day-to-day maintenance. The idea was that it was a dedicated group to concentrate on the reliability functions and also the prevented maintenance tasks. And so, who I reported to was the technical director of the company, and basically, above his position was our plant director. And that company was an international company. So, there was a support function working, kind from a global perspective and giving support globally to all of the sites worldwide. So, that gave a kind of a systematic and, how do I say, try to put that all plants into the same format more or less, thinking about this reliability functions.

I: And from your point of view, was that a good organization of the maintenance and reliability on your site? Or would you do it different?

P: Oh yeah, of course. The site was going through a lot of changes, a lot of job rotation, or a kind of like, a change in the work description, so it was a lot of changes while I worked there. So, all it was really, really (unintelligible, indistinct). So, I think that created some more challenge, that, when I started there wasn't a long history, no history at all at that site from this type of thinking. So, of course, that gives your time perspective, gives you a better understanding of what it should look like and how its needs to be developed. So, basically that time everything was new and it just put the organization together and basically trained everybody. What is this all about? So, I don't know. Did I answer your question?

I: Yeah, that answers the question, of course. Thank you. So, the next question: Does your site already have a stand-alone reliability engineer department? Well, you said already you had one, yeah.

P: Yes, yes.

I: This question is answered.

P: The current one doesn't really have it. So, it's (unintelligible, indistinct).

I: Why is that, because it's a smaller company and it's just building up. It has not really started its production alright?

P: Yeah, and also, I think that's kind of structure. My current company is part of this corporate of where the nuclear power plants belong, as well. So, reliability, of course, is really important in the nuclear power plants, as well as our plant, or future plant, that is going to be. But it's not kind of a separate function, it's more of a part of maintenance, maintenance engineers, or that it's like an automation mechanic corresponding person who's responsible on certain assets, or basically, we call asset engineer maybe. So, these types of functions are there, but it's not called reliability engineer.

I: I understand. So, if you think, not of the company you work for currently, or the company you used to work for but come companies in general. Why do you think more and more companies are introducing a stand-alone reliability department?

P: I think, that there one thing might be, that the stand-alone, that separate functions, stand-alone, it's maybe easier to measure. What is the benefit, what are the benefits? I also, what I see, that the biggest benefit is that you actually take the guys out of fixing the day-to-day problems. So, it should be a long-term development, a long-term function. Of course, you can help in one shift, every now and then, and participate in the daily maintenance activities as well. The goal should be in the long-term development and long-term improvement.

I: And have that, well, when you think on your position when you worked as a reliability manager. Where that the same reasons why you started a stand-alone reliability department at that company or are there any other reasons for that?

P: I think there were other reasons that were behind as well. I think that there was a global need for all the sites to get more out of their old existing assets and also to basically have a kind of supporting function on measuring the overall equipment efficiency and that's the things that basically you have. You have the supporting functions to actually do something about this as well. Not just to measure it.

I: Yeah, now the next block of questions is about expected savings through a reliability engineering department. So, what types of improvement and savings do you expect from implementing reliability engineering department?

P: I think, improvements, yeah, what comes to my mind is, one of the first things, for example, is that in some criticality analyses, it was not done or really not up to date at that site. So basically, you understand where is the focus, what are the key equipment of the sites, where to put some investments, or what are the weakest links. So, put your focus on the right things. I think other improvements, some come in longer-term. Like cultural changes that you don't freely appreciate, the guy who is fixing the problems, but you put more effort into preventing the failures, for example, and sort of things.

Also, don't let, in the long-term, let the failures manage you. But you can actually manage the failures, for example. In the condition monitoring and so on. But the savings, the savings part. Of course, when you do some improvements and decide that this needs some improvement or some task to be done. Of course, you have to evaluate, what is the cost of the work compared to the gain. So, it comes from there, and then you can best measure afterward that did you really achieved that saving that was planned before starting the project or the tasks. And it is really important to measure and to document the savings. So, when you accomplish some smaller projects even then, it's really good practice to document it and so that within X amount of time you saved this and this much. Either save directly some money or working hours or save production.

I: And can you quantify these expected improvements or savings. So, for example, in, well, I would like to save so and so much percent in maintenance budget or would like to increase production by a so or so much percent. Are there any numbers?

P: Yes, of course, you can look up all of the basic return on investment type of calculations. You can change more or less everything to monetary savings when you just have enough imaginations. But with many times its pure maintenance or equipment related and critical equipment that you can actually gain more or, how to say that, you get the failure, mean time between failure longer or it's quite easy calculations that you can do. If you can get rid of half of the failures, how much savings does that take in one year or three years.

I: And have those improvements or savings been achieved in the past when you worked for that company?

P: Yes, I would say so. And of course, it was a relatively short period of time, so, of course, when you do some sort of investments. Investments, for example, investing in condition monitoring or in lubrication of whatever are the easiest ways. Of course, when you just wait, that the next failures will come and basically you can prevent those failures. So, then the clock starts ticking after you started those investments. So, my story in there was just less than three years. So, it was a little bit short time period to actually measure all the monetary savings.

I: Yeah, and how did you track the efficiency of the reliability engineering, have there been, for example, any KPIs or so?

P: Yes, I think, we had two like weekly KPIs and then some (unintelligible, indistinct) or monthly KPIs. We tracked how the, like each of the technicians, for example, they had their own projects to run. So, we tracked how those projects were progressing and there was one KPI for everybody. For example, and it was just introduced, kind of, like mean time between failure, KPIs for certain critical equipment what had problems before. So, we took track on those ones in case there were any problems or failures

there was sort of like root cause analysis type of (unintelligible, indistinct) learning from the failure KPI as well, so. How many RCAs in a certain time period?

I: Are there any other aspects, you see the effectiveness, for example, in, well, the decreasing of production loss or any things like that? Have you looked at that as well?

P: Yeah, I think we took one site KPI from the plant OEE measure, so, of course, the failures that affect the OEE, those were one, one trigger for us as well. But that was not in, basically, it came in as even, the OEE figures. So, we didn't measure it our self, but we use that KPI to trigger our own actions, for example, the root cause analysis.

I: So, now, if you take all those costs into account what do you think are the particular advantages of a stand-alone reliability department?

P: I think one aspect on that one is what I thought, thought about it is that when you separate, you can actually quantify the costs and then you can compare that. Whether it's better to have it as an in-house function, or can you buy it from the reliability service providers, that's possible. How much would that cost? So, what the external consultants or the consultancy company do something more efficiently or better than your own team. So that gives you some sort of, or tools to compare. Do you actually get enough out of your own team? In some cases, might be that, okay, this doesn't really, all the guys are doing wrong things, or they're not qualified, or there's a lot of changes in the organizations that you cannot keep the focus or something is troubling your progress. It might be better to purchase that service from another company. And I think that's is a good choice. That's one aspect of how a separate engineering company would come as a benefit. And also, the focus thing that I mentioned before. When there is a separate reliability function, they should focus on reliability and not running behind the failures on the daily tasks and so what.

I: Okay, thank you so. And coming already to the last question and this one is: Would you like to add or elaborate on any of the questions before? So you have the last word, so to say.

P: Year, I wrote down one of the questions: Compared to a conventional setup. So, that is another question as well. You can question what is known as a conventional setup?

I: Well, yes, conventional setup in this understanding would be probably a maintenance organization like we have it in the standards, the written standards. So, we have the German or European standards, and they don't mention reliability engineering.

P: So, it's not even there.

I: That means a conventional setup in maintenance here.

P: Alright, I was thinking of more of an integrated setup, that's basically the maintenance engineer or technician is part of the team and not as a separate or/

I: That happens quite often, I think, that reliability it's not called a reliability department, but the people work in the conventional maintenance organization as reliability technicians or engineers, whatever. But they don't call it that.

P: Yeah.

I: Okay, thank you very much for your help.

8.7.7 Transcription Participant #6

Transcription

Participant No. 6

- Further information on the participant: See table in the appendix
- Date of recording: 23.11.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 57:14 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: So, the first question will be: Which is the position your work in at the moment?

P: Works engineer in (current site) pigments, color pigments plant. So, I have under my responsibility maintenance: electrical, mechanical, instrumental, and new investments department. Also under my responsibilities, the PSM process safety management office and also the energy manager.

I: Perfect, and in which positions have you worked before, maybe in other plants as well?

P: Okay, in the previous plant I worked and where I can comment, I'm still an employee. So here, for a certain period. This is (former site) TiO₂ plant in (region), Italy. And in (former plant) I worked in several positions. I (unintelligible, indistinct) engineering department, when I was hired as a technician. Then responsible for the maintenance of the black end, so, black end area engineer. Then I was the production area manager for the black end. So, black end area manager. After that, I worked as a commissioning engineer and erection, sorry. Commissioning manager and erection engineer for the new plant. It is called master plant. An investment of 40 million euros from 2012 to 2014/15. After that, I worked five years in the reliability department, as a reliability manager. Then, another year, always in (site) as a responsible for their maintenance, for the area maintenance. So, all of the areas. So, the part of the maintenance that is fronting the plant, the budget or expenses the routine maintenance. Except for CAPEX, except electrical and instrumental maintenance. So, I had, I was under the responsibility of the maintenance manager. Okay, now it's, I'm in

(site) for a new experience as a works engineer. Very little different department, much fewer people but the responsibility of joining together most of the maintenance and the investment and the engineering department.

I: Thank you so, you have partly answered the next question. The next question is: How long have you been concerned with the topic of reliability engineering. So, when did you start to work in reliability engineering?

P: Okay, in the reliability department I have started in 2015, May, May 2015 up to the end of 2019. So, complete for a half year.

I: So, it's a long time, is a long time, yeah. So, the next question is a bit more complicated. So, can you explain in, well, easy words, if possible, how's your maintenance organization structured, at the plant, you're currently working, and how is reliability engineering integrated there?

P: Okay, here are, the structure is very slim. There are three responsible: one for the mechanical maintenance, one for electrical maintenance, another one for the instrumental maintenance. They have one or two coordinators, then there is another two people. One is the responsible, and the other is the coordinator for the new investments. And then also another, another person, for the DSC and the engineering manager, the engineering, oh sorry, the energy manager. Also, the reliability that's, here in (site), that's a reliability specialist which is another one, another person, under my responsibility. So, he works in parallel with the three maintenance responsible persons that I told you before. This person has left in August, the one that was here. And now we are hiring a new one. Here works through people of the contract, so contractors. So, one lubrication expert contractor, and one inspector.

I: And, well, from your point of view. What should a reliability department look like? Is it the way it is, especially in regard to reliability engineering? Do you think it's very sensible and good at the moment, or would you like to change it, would you like to make it different?

P: Okay, as I come from (former site), which, maybe, the topic was largely, more largely developed, and the reliability department was 15 people. So, more than here all of the structure. I think that that's a lot of room for improvement, here in (site) for improving the planned inspection, the planned maintenance, the way how all of the lubricating and inspection a performed, must be better organized, better saved into the system, the operating system. Even to give evidence for the audits and specially to improve the way or the capability, possibility to have more predictive capability. So, I'm starting in the next, the last two months to create knowledge for the vibrations analysis which here was not at all. So, the inspector of a contractor with an instrument will start to make a route. To perform a route, that now I think there are 42 rotating machines. We have met a contractor with an external expertise company, to have a quarterly review

and analysis of the vibrations. The vibrations are taken by the inspector, but are analyzed by the external expertise company. This is on a quarterly basis, of course, we had already done at two days in classroom, and also in the field training for the coordinator of the maintenance, the responsible for the mechanical maintenance, also, of course, the inspector himself. So, this is an improvement, a start. Also, thermography can be developed especially for the electrical analysis. I've seen, more or less, what they already doing as an instrumental, predictive, preventive maintenance, and also electrical. We are doing a good job, can be improved with more sophisticated instrumental systems. These days we have bought a stroboscopic lamp in order to, for the inspector, to check and verify the real rotational speed. Not basing just on the target of the electrical motors which can be creating some mistake. And so we are implementing also the strobe capability. Other techniques can be useful, so, can be the ultrasound inspections, and then I will be happy to stop for a while. Of course, other techniques can be applied there, or slightly applied, but can be improved. Such as the thickness measurements, buying an ultrasound, or something that, for example, magnetoscopic check off the welding and so on. Of course, the resources are very slim, very little, so, let's do it step-by-step. So, my first quarter is, in these days, will be completed or will be starting, the vibrational capability. For the electricians, so we start there with the thermographic capability on the MCC panels. Then the next two important goals with the bringing all of the preventive maintenance that now is connected as insurance for the instrumentation that works in an external system which is a Maximo, and which we won't be allowed to have the licenses much longer, so my idea is to catch everything that is into Maximo and bring it to SAP. Also, develop the electrical part of preventive into SAP, which now is working outside with an Excel file, but in a very nice system that is very visually managed. Such as, I don't know, papers with calendars in the workshop. And the targets signed, written signed into any MCC. So, the system is working very, very well. From the point of view of the being very, very slim, very lean. On the contrary, maybe it is not easy, to show to some auditor or grouping together without a system into SAP. So, my idea is to bring it into SAP as well.

I: And this is mainly done by this one reliability engineer or technician?

P: No, ok, the electrical part is done by the electricians.

I: Ah, ok.

P: When they are not involved in the isolation procedures for the maintenance walks, they have a program to inspect and tighten all of the connections into the MCC. And any three months all of the machines of the factory are reviewed. So, cleaning the fastening and tightening the connections into the MCC. And very lean the system to check the inspection, but very effective from the reliability of the machines. Especially against the possibility of having fire into an MCC which starts from a spark of a loose connection. The next steps to improve also, but this is really, is already a very good

starting point is to make, to perform the thermography on MCC while is under tension, while is working. Just to identify and detect those components that are overheating and will be failing in a few or longer time. But I prefer if I have to choose it is better to tighten and clean every MCC out of tension. Any quarter, any there month.

I: Okay.

P: Something to improve that, of course, on a yearly basis the main interrupter is checked by an external company. Also, by (insurance company) the factory, as an insurance request. So, the biggest interrupter of the main power interrupter is checked during the general shutdown. So, in three years, they will be checked, all of them. The inspector will be walking with the area with the inspector to improve the reliability, will be the vibration with the external inspector. And the lubrication of the rotating machines, which is now done, but without anything written. So, the lubrication expert is sometimes is used as a normal mechanic, which is a very good mechanic, better than the other ones. As the capability of a reliability-specific mechanical worker. But, when making a lubrication, doesn't take any data, save any data. Not in a database, not in a paper, not in an SAP. The other, so first is to catch all of them: predictive, preventive maintenance, inspection, lubrication into SAP. That now doesn't work for that. Just what for the normal routine. The maintain from the request of the production we can be some way predictive, not because there is indicating inspection with some non-destructive technique, but because the production can see some misfunction, like low flow rate, noise, vibration in general terms and so on. So, as a result of the planning of the request of the productional and normal maintenance is performed and that is saved into SAP. As a notification into SAP and work orders into SAP, request (unintelligible, indistinct), and so on. So, the room for improvement, the first is SAP for all of the reliability aspects of the maintenance, the second one is to create a mechanical integrity program. At this moment, the PSM is reached the final goal to have identified and reviewed all the other studies for all the E&Is. So, the factory is covered 100 percent by E&Is and they are reviewed all the scenarios. There are 56 scenarios in the EHS tree identified. Now the next step, where also the reliability engineer will be working, is to identify the critical machines. So, guards and the instrumentation, rotating machines, fans everything that is connected to these 56 scenarios. I think 100 critical functional locations would be identified on those, at least, a single cycle plan of inspections and also maybe some preventive maintenance will be identified in my idea is to set it straight down into SAP. So, these will be the first goal of creating a system of checking those machines that are EHS critical. Then the use and the interconnection between reliability with inspections and the routes and also the responsibility of the mechanical maintenance and not only mechanical but instrumentation and electrical, will be there to work together in order to avoid any natural running to failure. Those machines that are identified as critical. So not, maybe they are already doing something like that, based on the experience, but nothing is written anywhere. No, so, the mechanical integrity program, at the end of today, means to have the systems working. The first step, of course, identify the machines according to (company) EHS 475 procedure,

criticality evaluation, which will produce the least of the EHS critical machines on the basis of that list. Some inspection programs and preventive maintenance will be set and performed. The final step to review those decisions, is working as a cycle. So, from the single-cycle inspection to the planning into a program and predicted maintenance and avoiding the run to a failure way of work.

I: From what I understand is, you don't have a reliability department, a stand-alone reliability department, but a lot of people in your maintenance organization do reliability tasks. Is that correct?

P: It is correct, it is correct, is much correct. For the electrical part, the main way to, is making this preventive maintenance, which is an inspection and tightening, cleaning these MCC. Nothing is done on the motors. For the motors on the field, are not, nor thermography, no cleaning, they are run to fail. The electrical, the instrumentation part makes a lot of calibration, testing over-limit switches levels, or calibrating levels, or checking pH-meter. A lot of pH-meter are checked every day. So, this is the preventive maintenance that is done. Straight from the department of the instrumentation on one side and electrical on the other site. Mechanical, the mechanical part is more complicated. Of course, there are more resources, is more chaotic. But this is quite normal for me in a chemical plant. Of course, on those machines that are historically identified and known as critical for the production, also for the safety. They already know how to make preventive maintenance. For example, there are a lot of fans that extract the air from the dome of the silos of stocks. Which basically have (unintelligible, indistinct) inside. So, the ventilation of this extraction fan is important to avoid the possibility of explosion. So, this fan is better than a normal machine that runs to fail. Of course, the other important factor is the stirrers. The stirrers into this big, big tank. The tank of 1.000, even up to 2.000 cubic meters, which performed reactions and the grows of the iron-oxide pigments, which will last three, four, five days. So, a batch will last for several days. These stirrers are really huge and they have, vocula, what's the name? Sliding bearing on the bottom and sometimes even in the middle carbon sliding bearings, which works between the coupling of a duplex steel main inside and an external part which is made by anti-wear plastic. Normally is a P6MX1, I think. The plural. So, those bearings work into the pigments which is a wearing. So, you know, you must know, that one tank you have to shut down for a week. And replacing the wearing elements every six months, and another one once per year and so on. So, they know those critical machines that have to be reviewed any six, one year? So, this is the preventive maintenance that is now installed and performed. Some other machines are overall would during the shutdown, which is scheduled for the mid-August every year, two or three weeks. So, packing machine, palletizing machine, generators, pumps and so on. There are a lot of machines that are overhauled completely. So the mechanical maintenance day-by-day stands to run on the production little request day-by-day, daily. On six months a yearly basis, organizing major shutdowns, are organizing preventive maintenance where the rate of wear is well known. For the wear of reliability of more complex machines, which if you don't overhaul once per year, at

the end the stop to be reliable. One of the stops is a made, not in a very documented way, is not well organized can be improved that. Of course, it's good that we have the capability to do that, the knowledge. So, as soon as we have expertise in maintenance, it is, in any way, the result is quite good. It is important that the reliability specialist work together with the expert maintainer. Will be caching data also into a mechanical maintenance program which can be something more than only the single-cycle inspections. Also, the planned year and six months and three months shutdowns. Especially for the future. But this is the state of the art and this factory looked through the eyes over myself, which arrived from a different plant. And maybe as some of the capabilities, more specialized, more well known, maybe only more, we are maybe in (former site) more conscious, to, that we are doing planned preventive shutdown maintenance on a few days, monthly basis, or on a yearly basis. Here they do, maybe they think they are not, everybody says into the factory that maintenance is just run to fail, but it's not true. It is run to fail those little pumps, little pipes, that can be run to fail without creating some mess from the production point of view, and especially from the safety point of view. In the other cases, some preventive maintenance is done by year, by historically sort. The exercise is to catch into an SAP program for the inspection and from the maintenance. Of course, improving the capability of predictive maintenance, by use of non-destructive systems like a vibration or other systems can be help which should be approved by the responsible for the mechanical maintenance and the reliability specialist, reliability engineer, at the end of the day. Here is called specialist, but it's a reliability engineer.

I: If you look in the future, would you like to introduce a stand-alone reliability department?

P: Okay, from the point of view of the existing structure it is already stand-alone. The only problem is, that it is just one people, one person with two external people. But it is not below the mechanical maintenance, is in pair. So, my responsible, of the continuous responsibility for the mechanical and instrumental, the new investment and in pair is also the reliability. So, imagining to have larger departments they are, can be considered stand-alone, even if the, by mutual interaction that the reliability is improved, not by standing alone and working on topics, that the final user is not aware of. So, it is important that the mechanical engineer, the responsible for the mechanical maintenance would be on board in the development that the inspector and also the reliability specialist can improve the concept under control. So, I want them to cooperate a lot, in order that all of the stuff that must be kept under control, from any point of view, from the reliability point of view, safety point of view. Also, documental point of view. So, audits, mechanical integrity, PSM, and so on. Can be passed from the mechanical to the reliability department. In this case, the reliability specialist. And so, the reliability specialist can be a help from the mechanical maintenance, but on the contrary, when the reliability specialist asked to before, a maintenance, or asks a maintenance. As a result of an inspection, vibration analysis, or by a due date over some preventive maintenance, I wanted them to interrupt in order to perform the

maintenance, and to avoid to jump the maintenance and run to fail will working. Which now is maybe in place. So, some machines are run to fail. I don't expect to run to a zero-failure mechanism maintenance, but to make a little improvement. Of course, also KPIs have to be created, and want to read about that. Without any zero that is. Cost control on very few. Also, SAP has to be developed to have an important operating system as a tool. Now SAP is not completely configured, like in the other TiO₂ plants. So, it must be configured by external suppliers, by external programmers which to be developed, to be developed a lot. So, all of these packets are to be developed together.

I: Okay, looking to different companies, not your own company. So, what do you think why do more and more companies introduce a stand-alone reliability department in the last 10 years, maybe.

P: My opinion can be, just thinking and talking, that, maybe one weak point, one weakness of putting the reliability under the responsibility of the maintenance can be jumped by fast, sucked into the day-by-day routine is aspects, every day working in production and maintenance. So, if you don't put outside the reliability, the reliability is sucked up into the routine, the routine of the production and maintenance. We are working which it doesn't look far away, sometimes, but looks close to the day-by-day problems. So, it's important, it's well spent, to defend the reliability from the time consumers of the day-by-day routine maintenance. So, the urgency that is asked by the production is, maybe, always very hard. But reliability cannot be working on such a basis in a proper form. So, if you put reliability under the responsibility of the one that has to perform the maintenance before the end of the day. So, maybe, we lose something from the point of view on longer terms.

I: And that is why you have your own reliability specialist there.

P: Yeah, the reliability specialist could be put under the mechanical maintenance as a coordinator of (unintelligible, indistinct). And on the contrary, is put under my responsibility as a separate task, near to work together, and my responsibility, my scope is to improve the collaboration, cooperation. But, putting one under the other, at the end of the day, it became another day-by-day coordinator, which is not the value, the added value, of the reliability. So, I think if companies now start to understand that and they see that improving the reliability of the plant, is a really added value, added value from the safety point of view. Also, from the business point of view. So, a more reliable plant is making more money, than just thinking that correcting those problems that have been identified by production at the last minute before so they asked a four a clock, and you finish at three, three-fifty. You think that you make ten minutes more of production. On the contrary, if you sit down, analyze, so you make engineering and maintenance by means of reliability. You can maybe understand that problem can be avoided at the start. More or less 100 percent of the other problems that are the urgency or the production to maintenance can be avoided at the bottom, so at the root. So, of

course, it is really costing from the resources, time, knowledge, specialization, non-destructive technics, lot, a lot of stuff. But if you work well on these, the plant is more reliable. It improves the EHS for the environment, from the safety, from the health and they create more product, more business, better quality, no strange things happen and so on. Here in (site), we are their starting point. Not well conscious of what they have already done in the years, even because this company was owned by a single person, so it was a little Italian company owned by the owner which was also the director who knew any design, any part of the plant, but maybe didn't have so in mind the possibility of improving in a really realistic way by the means of a reliability department. So, maybe it was just (former company) before, and (company) now, as a company to introduce the position. Even if it is only one position at this moment. So, my idea, it will be to, if possible, so add more people, reinforce all of the staff in maintenance. Because maintenance is very, very little staff, especially for the mechanical maintenance, and very little staff for the reliability. So, and also the construction on new investments so these are three parts of very, very weak.

I: Okay.

P: And it will be an improvement to enforce that like in, for example, in (former site), also in (another site) we have. So, much more people work in, producing good maintenance, and improve the reliability of the plants.

I: You have almost answered my next question with was: Which types of improvement and savings do you expect from implementing a reliability engineering department. But you already answered this question, I think.

P: One thing to add is these: Some months ago, when I arrived, we started, together with production, maintenance, and production to have different weekly planning. So, before the requests were grouped by the reliability specialist, the previous one, grouped and faster to the maintenance expert, the maintenance responsible, which was a mess. Because, they were not in the same room. The contractor with resources, the responsible with the budgets and the spares, and the production with the availability of the part of the plant. So, since July, we started to make a weekly program, a weekly program on Wednesday, which is more or less all created the level of employment for the resources of the contractor. So, the contractor has one day to look for extra resources, or fewer resources, which never happens of course, and the day after each based on the resources that are found by the contractor, the main contractor for the maintenance. The program is set and is signed, by, altogether, by moving from one day to another accordingly to the availability of the machines. This program, is, must be reviewed every day, and there is a weekly review. So, for the next day is reviewed by the daily production people: Shift production manager and the mechanical maintenance people and so. So, this is a starting point, a prerequisite to give the possibility tomorrow to the reliability to bring the weak signal, the weak signal that can be found on the machines or anything else, in order to make predictive

maintenance. Without the day-by-day review and the weekly program, we just run to the one that shuts louder, from the production. So, which is not but the way that we can be working in this direction. After these, all of the improvements, are the ones that I already said before.

I: Yeah, the improvements, of course, you said all the improvements you want to make with reliability. But can you quantify those improvements? For example: I expect with reliability to save ten percent of the maintenance budget, or whatever. Can you state that in numbers, somehow, what do you expect?

P: My point of view, my point of view is not based on the own analysis of figures from the former year. I must be honest, that these exercises, I didn't do, up to now. Personally, I believe, based on my previous experience, that more than saving some money of maintenance, we can have much more reliability of the plant. So, producing better and more production. This can be an important plus that twenty or even thirty percent.

I: So, you mean you're reducing the loss in Production.

P: Yes, reducing the losses in production, in EHS, in quality, and also in the quantity. So, this is something that I've seen in (former site). Trying to improve the predictive capability and planning all of the problems and try to fix them in meaning, very little day-by-day shutdowns, at the end we don't save much money. After one to two years, we still don't save much money. We spend the budget, we don't spend less than the budget. Maybe, based also on the attendance of maintenance of spending the budget. So, there are always problems that you see as minor when you have the biggest problem. But, when your biggest problem is fixed, by very good maintainer doesn't try to save money and leave the other problems there. Because, they know that today little problems, will be the biggest problems tomorrow. So, at the end of the day, they always spend all the money there are given, as a budget, to make better and better they work. So, when the biggest problems are fixed by means of reliability, planning the maintenance, and production, and all of this system is working together as gears into a gearbox, little problems can be faced much previously and fixed. Spending less money at the end of the day. Especially improving a lot, the reliability of the plant. So, the plant's steady-state can be run at much more capacity. In (former site) seen these figures in terms of ten, twenty, twenty percent.

I: Okay.

P: A thirty percent more, of course, the timing, where you need, when you need to work together, from reliability and maintenance and production is more or less months or years. So, several months for at least some years. After a good way of working, reliable way of making maintenance. All of this staff, working together, you have an improvement on the capability of the plant, in terms of quantity and quality.

You can also lose by trying to save money, so making a cost-cutting on the maintenance budget after some months. Maybe, six months you ran the way, the same way, more or less. Then you start to lose production, more or less, you go in urgency, more run to fail, more and more and more. At the end, you ran everything to fail and every day you lose thirty percent of the production budget, according to the same capability of the plant that you use for 100 percent. So, you tried to save 30.000 Euros which is 10 percent of the maintenance budget. After six months it's okay, after another six months you lose something. After two years you systematically lose 30 percent of the production. And, maybe, you spend even more, on maintenance. So, this is the result of not caring about reliability.

I: So, how do you track the efficiency of reliability engineering? So, KPIs for example?

P: At this moment, we don't have KPIs in (site).

I: Not yet?

P: This is something that I was saying before is to be set. We don't have a basis from SAP. It's very difficult to understand which is spent on reliability or predictive instead of (unintelligible, indistinct). So, we really have to improve that.

I: Okay, yeah.

P: At the start.

I: So, you don't have any measurements for reliability at the moment?

P: No.

I: Okay, so/

P: In (former site) we had something. That has to be created. We have to create reliability. So, it simply engineered the KPIs (unintelligible, indistinct).

I: Of course, I understand, yeah, here, so I think, even this question you have answered already. So, if you take all the costs into account, because reliability, your specialist, costs money. So, the people out of maintenance working in, more or less, doing reliability tasks cost money. But even if you take all these costs into account, what do you think are the advantages of a reliability engineering department? But I think, you have answers that already. But, can you answer that maybe in one or two sentences?

P: Of course, based on the fact, that any failure that you have now, for example, you substitute a pump, because the seal is broken for one month. Then you change a pump, you spend 15.000 euros of just spares, on an overhaul of the pump. By the means of creating an inspection route, and checking that the water is well working in the barrier

of the seal. That seal can fail once any five years instead of two, twice per year. So, at the end of five years, you have maybe 100.000 Euros in your pockets. This is a very poor example that states the power of reliability in predicting systems to avoid the fault three on the machine. So, from a little misfunction to the destruction of the machine. In fact, on the important, in big, costing machines, the already overhaul and checks. On the little machines, we don't do. But, at the end, we substitute pumps that could be avoided. So, at the end of the year, maybe, you change (unintelligible, indistinct) of fifty. Which there is, maybe, 5.000 Euros per pump, is different over 250.000 Euros, so up to a quarter of millions of Euros. Only failures, to fix, failures that you could avoid by preventive and predictive inspections, reliability at the end of the day. Things that maybe do production, in a little way. At this moment they, also the inspector's tasks, some of these, some checks on the (unintelligible, indistinct) filters, for the environmental aspects, checks of the water barrier of the pumps, but not in a really well-organized way. So, all the improvements must be done.

I: So, coming to the end, would you like to add or elaborate on any of these questions, anything you would like to add to the topic of reliability engineering?

P: Oh, sorry, I don't understand.

I: I said, we are coming to the end. So, you have answered all the questions in this questionnaire. Is there anything you would like to add to the topic of reliability engineering? You have answered a lot of questions and said a lot. So, is there's anything you would like to add?

P: Okay, there is one thing to add.

I: Okay.

P: In my personal experience in chemical plants, that run to batch, especially to batch. Because my experience over steady-state running of chemical plants is less. My opinion is that at steady-state plants you must be fixing and keeping running the system as much as you can, and arrive to a planned shutdown. Only batches, batch plants are more concerned of using the moments between the one batch and the other, if you have room to make some maintenance that disappears as a loss of production. But also create a lot of destruction of the maintenance. So, my personal conviction has been, is, because my experiences has been, that on plants, complex chemical plants, which run steady-state plus batches all mix together, with little buffers from one section to the other section. Like the TiO₂ plant, but also this plant is the same, is to create, at the end of the day, starting from the run to failure way of working and arriving at the next step, which is not the one that we have here, but maybe, sometimes I had in (former site), not every day, is to arrive to planning on a monthly basis, for example, on a monthly base, also one a yearly basis, with the general shutdown, but also creating a plan a week, all week in a month. When you plan measured shutdowns

at some phases, explain better/ Your steady-state running is 100 percent capacity, so you want to make the budget, you don't have to lose production. But, you decide, as production manager, to shut down one kiln, so, one section, 100 machines that are related to the kiln. Once per month, so, for example, on the third Wednesday of the month, you shut down kiln number one. The Thursday, you should down another piece of plant, another group of machines that chained from them together. So, when you stop one, to make maintenance of one machine, you have maybe 100 machines stopped together, because they are connected. So, you have to try to organize, in a planned way, the shutdown of this line, of this section. So, everybody knows, that particular day every month, without arguing about stopping or not stopping. You will be starting and losing production on those 100 machines. Okay, suppose that there are 100 chained machines, connected machines. And maintenance is asked, to fix all of the problems that are arriving to that shutdown. So, this is one way of creating an agreement between, inside the manufacturing, between production and maintenance. Of course, what is the request? The request? The final goal from a production point of view is that that section will be working at steady-state with very minor problems to the next shutdown, planned. So, don't state to shut down a line, because there are problems. But, the state from the beginning of the year, that any suppose for weeks or more. Any third Wednesday of the month, you shut down that particular section of machines. Of course, that day, the resources of the maintenance must be quite high to fix twenty, thirty different tasks and in a more reliable way. So, don't, not just fix, but make a very, very good and reliable job about the best expertise, the best expert, also the better maintenance. So, create quality maintenance, but in a really planned and already agreed on way between production and maintenance. This is something that I've seen in (former site). I personally did, in the, from 2009, 2010, 11 and 12. Works, it works, costs the budget. Not saving much money, but not spending more than the budget. Of course, you need many, many times to arrive to this way of working with a lot of engagement from everybody, maintenance and production. But the rate that is there, the throughput of the plant is much, much higher than the normal way of working by running to fail. So, it's thirty percent more in quality. This is something I had experience. So, a really arrival point can be that, according to me. Not to wait until you have a problem, in order to organize a shutdown. Because, at the end of the day, you maybe shut down 100 machines you make five tasks. If you run to fail, you make one task. If you organize on a weekly basis, with five tasks on that line. If you know one month before that this particular day, it's already agreed, that line will be shut down. Maybe you make it thirty, thirty preventing, predictive, checking, fixing, inspecting. So, and you avoid a lot of failures. Any failure, that day you don't fix, you avoid, it will be a shutdown, unplanned of the same around to of the general monthly shutdown. So, that day, you maybe shut down for two shifts, Sixteen hours, you have, I don't know, a probe, temperature probe, that fails in the night and you have another full hours. You have a motor, you have another 10 hours. So, three failures, uncontrolled, make, produce the same amount of production lost as the general shutdown where you can perform, in quality twenty, thirty, tasks. While, of course,

put in the right resource in amount to point. Of courses, spares planned, detection of the problems, so, making also tests before in order to be sure on the diagnostic.

I: Okay.

P: This is not just an idea, but is my personal experience.

I: Okay, thank you very much.

8.7.8 Transcription Participant #7

Transcription

Participant No. 7

- Further information on the participant: See table in the appendix
- Date of recording: 09.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 44:54 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: And the first question is: In which position do your work?

P: I'm the site reliability Engineer. So, I'm responsible for 1,000 items of rotating equipment at (site).

I: And in which positions did you work before?

P: Previously, I was the asset engineer on the with end plant for 13 years. And prior to that, when I started at, was (former company) then, I worked three years, I think it was, in the projects design office. So, I have a very wide experience from projects to front-end, asset management on the with end, and then from September 2009, I've been involved in the ICON plant. So, I've been the site reliability engineer now for 16 years.

I: And how long have you been concerned with the topic of reliability engineering, and in what context?

P: Reliability engineering, I think, was my passion from a very young. So, mechanical engineers tend to go down the pressure vessel route of the rotating equipment and machines and machinery. You know, even from a young age looking at motor cars was always my passion. So you know, when I go back to I changed the clutch cable on my dad's car when I was 14 years old, and that was my first introduction to some sort of engineering. So, it's always been, you know, a passion of mine, I think from a very young age. My father was an engineer, you know, so he was a test engineer, worked on nuclear submarines and stuff like that and boilers. So, so very much bred from an early age to be a mechanical engineer, unfortunately.

I: And the topic of reliability engineering? When did you start with reliability engineering?

P: Reliability engineering started when I was asset manager on the withe end, and bear in mind that this is before the days of computers. So, you know I worked in an area where we used to go and talk to people, and we had written memos. We didn't have computers. So my first introduction to reliability engineering was looking at scheduling and planning maintenance. So, we didn't have an SAP system then. So, basically, my first experience with planning maintenance was the Sun mills, you know, we need to overhaul Sun mills. So, we had six Sun mills them. So, we actually did a Gantt chart. You know, basic on paper and stuck it on the wall, and said, right, we need to overhaul that one then. This one now. So, very much planning well before computers and we did that for (unintelligible, indistinct). We develop that for micronizers. That's a test. Some fire alarm is going up. So yeah, even before computers were invented with all these fancy software packages, we were doing that with charts that were on the wall with regards to/ so, Sun mills and micronizers were certainly the first things we looked at to make sure we planned inspections and overhauls. Obviously, when computers came along, you know, I don't know if you remember Lotus one-two-three that came out before Excel. You know, that was probably one of our first planning tools was using Lotus one-two-three.

I: Okay, thank you. So, what, well, how is your maintenance organization structured and how is reliability engineer integrated there? So, talking about your site.

P: My biggest problem with reliability engineering is our site is run by process engineers. So, we have a lot more mechanical engineers and engineers on site now. Then we probably ever done, so I would say, over the last few years, the integration with reliability engineering is probably a lot better than it has been in the past. I think in the past it's probably been right. We will run the asset within reason to destruction rather than planning maintenance on it. One of the problems we have at the moment is we have shutdowns every three months on our plant. And rather than doing everything that needs to be done, everything is tailored to a 48- or 96-hours window with the label that's available. And I think it's educating our management process colleagues that it's far better to get more people in or extend that shutdown window to get all that work done other than run for another three months with potential issues that can shut you down. I think we are improving on that; I don't know if you have ever met (name). He was one of the advocates on the site leadership team on (site). So, he was a good catalyst for getting that promoting reliability engineering and planning scheduling work, getting all the work done. So, he probably saw the catalyst of (site) we have tried to help us. (Name), who is our sit director currently is fully behind that. So, the conversations I've had with (name, site director), he's very much with regards to, let's get as much work we can in a plant shutdown event to minimize the risk of having a failure before the next shutdown.

I: And can you tell me something about your organization, so you probably have, well, a site director, then you have a works engineer, and where is reliability engineering integrated there? So, to whom do you report, for example?

P: So, we have the site director and site leadership team. So, in that site leadership team, we have the works engineer, which is partly (name). So, they meet as a team monthly, and just yesterday was the monthly meeting. There is a sort of define a strategy where we going at (site). So, that's the very high level, they meet weekly, as well. The site leadership team. So, you know, so (name) keeps us well informed, what's going on within the site leadership team. So, from an engineering perspective, we have our central engineering, which I'm a member of, that managed by (name, works engineer). So, we support projects new and existing assets. Also, support the plant teams and likewise gets support with (unintelligible, indistinct). At the moment, I'm doing a lot of work with our Malaysian colleagues. Supporting them with some issues I've got. And then, within the plant teams, what we've done is we have increased the number of engi/ mechanical engineers we've got. So, we used to have one mechanical engineer within the plant teams. Now, within the white end, we've got three mechanical engineers within the ICON team with currently three mechanical engineers. So, that's a huge improvement on the one mechanical engineer that we used to have as an asset engineer. So, what the mechanical engineers do within the plant teams is they look after certain parts of the plants but work together as a team. And I support them as and when required. I'll give you a recent example. This week is we have, you'll probably get to hear about these. We had two tier 1 diluted acid leaks on our withe end plant with a three-inch pipework leaking. So, I've been working with (name), the asset engineer on the withe end with regards to doing the RCA study. I'm sorting out the problem so to make sure it happens again. Be embarrassed that we had two tier 1 events on the same piece of equipment, but (name) has done an of the good work with a gust the RCA and I've been supporting. I was down having a chat with him and fed some information that I have with regards to other RCA is on diluted acid. So, he's doing that so, we are probably in a better position we have now, with the number of mechanical engineers we've got and reliability as an acceptable topic. I always refer to reliability as the necessary evil. You know, process engineers don't shut the plant down for maintenance. But we need to educate them that there is a risk and as long as, and I had some really good conversations with our site director (name). You know, I remember one, one conversation we had on a Friday afternoon for 45 minutes. Because I want to shut the ICON plant down. When I explained to the risks and, you know, we had the spare parts, that has to do with the Lawrence pump a number of years ago. And a Lawrence pump was basically shaking itself to bits, and I found that it was one a safety run. So, also (name, site director) good 45-minute conversation, and after that conversation, (name, site director) was fully brought into right. Shut the plant down, and let's change the pump. That for us is a 45-hour outage to do that. So, you're losing probably 5 or 600 tons of pigment at the cost of 500 tons pigment, it's gonna be up towards a million pounds, I would have thought, if not more. Then a few million pounds less to the business to shut one of our assets down to do that work. But, you

know, all I could say is, we are getting support with regards to reliability from (name), (name), you know, and the asset managers that we have within the plant teams. And then there all get it. They all understand, but it's a good thing to do, and it's all about managing risks. We have some issues on our ICON plant at the moment that I've discussed with the ICON plant managers this week, and I said, right, we need to change the equipment out in the April shutdown, we monitoring it weekly. So, (name) he's our condition marketing technician. He'll do vibration monitoring on equipment weekly. So hopefully, nothing else changes, it change will not prior April ICON 2 shutdown event. So, we got a good structure, and reliability is built into our structure. But it's all about it's a constant promotion of dialogue within the process engineering community and the asset plant managers. Just to make them aware of the risks and basically trying to convince them with data that we need to shut a plant down to do this work, or we need to extend a plant shutdown event to get these other things in.

I: And, well, now you're explained the way your maintenance and reliability organization is at the site, at the moment. From your point of view, do you think that's a good organization, or would you like to do it differently?

P: We can improve. Our problem at the moment is, we are getting young graduate engineers in. So, I don't know if Germany experiences this. In England, Great Britain, in my generation you always went into a job, may have been 32 years, nearly at (site) now. My sons, I had two sons, there are 28 and 31, so there are of the generation now where you only work at one place for four or five years, and then you move on, and you go work somewhere else. So, one thing that we learned when at (site) last time I looked at it, you probably looking at seventy percent of the workforce have been here, probably less than six years, you know. So, there are very few dinosaurs left at (site) with 20 plus years of experience. So, one of the things we had to learn is our procedures have to be robust. Because you're bringing in these new people, you train them up, and you can't rely on experience anymore, you've got to have very robust procedures. So, we have two people full-time employed at (site) who are writhing and updating our operating procedures, and likewise with our maintenance procedures. I mean, I implemented quality build plans, probably the about eight years going on, nine years ago I think when we started that. And had I not put that in place, we would be in a terrible position without workshop overhauls because, you know, we've got a high turn of guys in there. And I think the longest-serving guys in the workshops now been here for three years, going up four years. So, and quality build plans was, one fitter employed, full time for five years to write them. And I got a commitment from the site leadership at the time, you know, so like eight, nine years ago that that was what we wanted to do and that was the investment that was required and somebody full time at the shop floor to do nothing else but look at OEM manuals condense them into the quality build plans that we use now. And if you look at Lawrence pumps, I think we are on revision 38, you know. So, there have been at least 38 improvements to our quality build plans. If we didn't have that written and embedded in our organization, we wouldn't ever capture all the improvements we've done over the years with

regards to Lawrence pumps. And we got many more examples that Warman pumps is another example we learned a lot and improve our quality build plans that we do in workshops to improve reliability.

I: And if I got you right, so your reliability department is just you alone. Is that correct?

P: Well, not just me. Reliability you've got instrument control, you got electrical, you've got pressure vessels, and you got rotating equipment. So, in the central team those, we have a responsible person for each of those functions. So, we have instrument and control which we've got (name), and we got a new graduate engineer that is (name) helping to do at the moment. We've got electrical as another functional lead. So, we've (name), you know, we've got (name) who is training up at the moment. We've got pressure systems, we've got (name), he looks after our pressure systems and stuff like that and then myself. I look after our rotating equipment. So, within the central engineering department, we have the four functional leads, experts, who are responsible for the standards, the procedures, and I find my role now is a lot more mentoring young graduate engineers, you know. So, I'm taking one of the with the end engineers at the moment. I'm taking him through our management of change, purchase and coaching him through that. (name) we talked about, I'm coaching him about root cause analysis, you know. So, he is another graduate engineer we got at the with the end. So, yeah, a lot, quite a lot of my time at the moment is supporting the plant teams and helping and coaching them. I mean, quite often, I get asked to do something, and my response is: no, I'm not gonna do that. (name) you at gonna do this RCA. No, I'm not, but what I will do is our help, and coach one of the plant teams guys and support them, so they get the learning because also me doing it. I don't do them RCAs I'm doing them in sleep, have been doing for years. So, there's no passing on my knowledge and experience, bear in mind the clocks ticking, and I've got, you know, two and a half years left probably my career. If I do indeed decide to retire at 60, full time, and use that time to educate, you know, the new graduate engineers that we got. So, they can then take on that sort of knowledge and experience that I gained over the last 30 odd years.

I: Well, now talking about companies in general, so not your company or your site. Why do you think more and more companies are introducing a stand-alone reliability engineering department?

P: I'm working in a network of a number of (area) companies. So, all right in the last two years after, because of COVID, we have not met. Prior to that, we were meeting every six months. So, I used to meet offsite with, you know, you got (company), (company) is in there, so you got petrochemical companies, you've got fish, food manufactures, you've got corn, food processing plants, chemical plants (name). So, you've got quite a varied network of people in there, and predominantly the topic we discuss is reliability. So, think, all we do we choose a topic like communication within the workforce was one topic condition monitoring or lubrication we discussed and

shared information. So, basically, what we do is we look at best practice within the organizations and share that information. I'm pleased to say that (site) is ahead of the pack. Other companies with, we will, actually we probably ten years advanced with some of the other companies on (area). And that's I feel quite good about that. I don't know, when we used to go to these events with my works engineer time in (former company) quite often, we will come away from them and say, blimey, that's where we were ten years ago. So, I feel that we, we are ahead of the pack with the (area) companies. Probably with the exception of (company). (company) has invested a lot of money, and they got a lot of money in their reliability. With (company) work on the basis where they shutdown. One shutdown event every five years. So, there spent five years leading up to that shutdown, planning for that sort of event. Glad we're looking to get seven days runout of ICON plant in five years. So, we've got a different reliability strategy. Suddenly, you know, some of the work we've done with companies on (area) is, I think, probably the exception to that is sort of like, SMED. So, sort of SMED was some SMED, and some other activities that we've seen other companies is probably something that we've, we probably not that good at. But then is all depending on how your chemical plant operates. We haven't got time for stuff like that where obviously, I saw that a pharmaceutical company exercise very well over (city). And the process (unintelligible, indistinct) and they have quite a good sort of facility there, where they implemented a number of reliability strategies because they have the time to do it, basically, fitted the operational plant.

I: But what do you think are the main reasons why they started an own reliability engineering department?

P: Is costs, you know, it's it. You run your assets and keep spending it costs you lots of money. And I think it's getting recognized properly over the last ten, fifteen years that a pound spent on reliability is probably ten pounds saved. I mean, where are in exactly the same boat as you. When you shut the plant down, it's, you just add zero's on the end, what that costs. So, we put a number of reliability improvements in at (site), and we've actually paid for it, so, one of the philosophies we used. In fact, we're doing something next year with regards to a variable speed drive. And we got a number issues, and we've looked at how much that costs us, over the year, it's actually, rather than get capital, we can save money on our maintenance spend by next year, look at that variable speed driving and spending that money upfront on that piece of equipment rather than spending that money over the next year to repair that piece of equipment when it fails. So, it's making those sorts of decisions based on data with regards to rather than, you know, something. You take a Lawrence pump, for example, you talking about 80 to 120,000 pounds to overhaul a Lawrence pump. So, if I spend 30,000 pounds on an improvement on a Lawrence pump, even if we saved one failure in the year like that's more than it pays for itself. That's very much the philosophy around reliability; if we can make an improvement, it will pay for itself within twelve months, do it! That's our philosophy. So, that's how we funding a number of reliability improvements that we doing a (site). If it's longer than 12 months to 18 months, then

we will have that discussion with a plant team. If it's longer than that, then you're looking at projects and capital to implement than some improvements. So, a lot of reliability improvements we doing at the moment are very much in-house. Because they got payback within 12 months.

I: And for your site, I think there are the same reason why you do have a reliability engineering department, its costs, right?

P: It's very much cost, so

I: Or is there anything else, maybe?

P: Less pain, you know, just in fact, the meeting I just had before for yours is our Lawrence pump improvement plan. So, we have these big tetra pumps, and we go back to 2019, you know, we lost 14,000,000 pounds with the production and we would changing pumps, like going out fashion. In fact, we couldn't overhaul pumps fast enough to install them in our plants. Not only cause pain for the ICON team, it caused pain for me personally, the central team had to work a lot of night shifts, it caused pain for our workshops because literally, all they were doing, it was just overhauling Lawrence pumps. So, we got an invested lot of money in spares. We invested a quarter of million pounds in spares. So, increase the amount of spares that we had, and we also improved the way that we overhaul the pumps, we started up the pumps and put all procedures in place to manage that. So, because all the work we did in 2019 and 2020, we know now and can predict failures on our Lawrence pumps a lot better. One of the things that we're looking at doing, I had hoped to get done this year but is next year, we are moving towards WiFi online condition monitoring. So, we now got the equipment on site, I just need to get the form signed off and get that installed. So, we're looking at installing the at one pump, so that's cost me 8,000 pounds to install it at one pump. Because we put the firewall in place, the best station in place. If I want, put it on any other Lawrence pumps, on which we've got eleven. It's gonna cost me 3,000 pounds per pump.

I: So, that leads directly to the next question. So, what type of improvements and savings do you expect from implementing reliability engineering?

P: The whole point of reliability engineering is making the asset last longer. If we can get, so we know, we've got a project, we got a Warman pump installed, it's too big. It came (unintelligible, indistinct) wrecking mechanical seals. We get three to four months on that pump. So, we need a small pump to go in that. So, that pump should last at least a year to 18 months on slurry, not three to four months. So, we're looking at a project there, we've got the costs. We know it's about 12 to 15,000 pounds to overhaul a Warman pump. So, we've got the cost. We know the failure rate that can easily justify that project. The problem is at the moment, as you probably know, CAPEX is very tight. So, and that might be a project that we just said we are going to

take the pain on our maintenance budget rather than capital to push that improvement project through. Because we know, that it gives the benefits. So, the whole point of reliability engineering is getting the asset to last longer. So, you know, overhauling is many times during the workshops, you not spending money of spares and therefore, is a cost-saving. And I think, with the data that we have, all of that is easily demonstrated. Every tonne that we lose a (site) is accounted for. And we have that information fact every morning just looking back to 2014. I think we've got that information probably going back to 2020.

I: Well, that actually leads to the next question. So, can you quantify these expected improvements and savings? So, for example, in the percentage of maintenance budget?

P: Yeah, what we've done is we've got a number of, you will be familiar with the term, blue chip projects.

I: Yes.

P: So, I'm managing Lawrence pumps which is a blue check project. I had two blue chip projects last year. So, I was looking at, what I call, the top six. So, there were the six items of equipment on this site that caused the most pain for reliability. So, the decision was taken in 2019 for last year and this year that, because the improvements, have given us the benefit. So, I called the top six. Just concentrate on Lawrence pumps, so with regards to Lawrence pumps, we have an A3 plan that I report on every month. So, we look at what we spending and what we saving, so we can say, I mean, just on the downtime data alone, you know, if we can improve the reliability of the pumps. So, we don't have to shut down and lose tons. To do a pump change. All that is easily quantifiable, and I know what the maintenance spend is on Lawrence pumps. And also, I think, the decision that we talk to increase our stock holding by a quarter many pounds and bear in mind some of these castings were on three to six months late time. I've just been ordered two impellers this week for a Lawrence pump. There on a six months late time. You know, the plant team wants to install one of these impellers in our April shutdown, and I said, we are not gonna get them, I'll try to get it delivered before then. We might get it for May next year. But I wouldn't expect to get installed ready for the April shutdown. So, yeah, we are very good data on our maintenance costs, our downtime costs spend. So, we can quite easily monitor that, and we do that via our A3 plans.

I: And have those improvements, well, been achieved in the past? Can you show that, well, not to me, but then you show that by numbers that you achieved savings to reliability engineering?

P: Yeah, I mean, if you look at the Lawrence pumps, alone. You know, we went through a period where, September 2009, I got involved with Lawrence pumps, this was, apart from plant shutdown events, it was our biggest loss of tons on this plant.

We put in improvement plans until we got to saw of 2016, 2017, were a loss of tons, you could measure in hundreds, not thousands a year. And then, yeah, the wheels fell off the wagon in 2019, and that was mainly around lack of experience and the lack of spares. So, our site leadership team, a wrong decision in my opinion, there decided we only need one spare Lawrence pump. Even though we have four or five of them installed on the plant. We should keep two spares to manage the risk, but because it was 100,000 pounds to overhaul a Lawrence pump. They left it in bits, in the workshops, weren't happy to spend that money because our maintenance budget was overspent, and they didn't want to add another 100,000 pounds to it. So, on the 14th of January 2019, when we had our first pump failure, we changed that pump, and we didn't have a spare. And in the workshops, even working around the clock, you look in a week, working round the clock, two guys working twelve-hour shifts, to decontaminate, strip, inspect, rebuild, test run a Lawrence pump, so it's available when starting the plant. And, pleased to say now, I have the commitment from our site leadership team that we have two spare pumps for each size that we have. In fact, what was it, our workshop supervisor just said to me, last month that this is the first time that he has no Lawrence pump to overhaul. Because there are all overhauled, test run and set the rack. He's got one pump. We changed one pump this month, I expected him to have that overhauled before Christmas. So, we will start the new year again with a full rack of pumps.

I: So, how do you track the efficiency of reliability engineering? So, do you have certain KPIs just for reliability?

P: We have quite a selection of KPIs, and they're all on SAP, so you're looking up a backlog of work orders, for example. A lot of it's managed around the number of work orders that you have in the backlog. So, that's how we manage the KPIs in our Tier 3 meetings that we have monthly. Sorry, we have Tier 3 meeting weekly on a Tuesday afternoon. So, we look at those KPIs and (name) go through those. But they're very much SAP generated. So, it's to do with backlog, number of work orders, routines that we in backlog, and stuff like that. So, of the things we're doing at the moment is reviewing our routines. So, are there the right routines at the moment to deliver the reliability of the equipment. One guy said to me many years ago. He said (name) why do we monitor the temperature of bearings on Warman pumps? And I said, well, we do, why do that monthly? When was the last time we had a bearing failure on a Warman pump? I said, well, you gotta point there, it's been a number of years, so that was in that instances about what we do is that valuable data and is that going to prevent a failure? So, I agreed with the supervisor a couple of years ago. Okay, we'll cancel that routine. Because it is adding no benefit to the monitoring the failure of the piece of equipment. So, what we do at the moment is, we'll reviewing our SAP planned routines and looking at them. Are they adding value? And improving reliability on that of equipment or preventing a failure. So, that is the sort of exercise we going through at the moment.

I: Are there any other aspects that you can use to see effectiveness, for example, reduction in loss accounting. Or, sorry, reduction in production loss?

P: We were very much, I mean, you're gonna get this. We got consultants in this year, and I suspect it's going to be rolled out to other sites. This, with me being a dinosaur, this is the fifth time in my career I've been through this experience. I know you have been through it as well. And it's a painful sort of experience, is not a very pleasurable one, but it's very much driven to improving the tonnage and a lot of that around eliminating the equipment failures, improving reliability. So, we're going through that painful process at the moment. So, yes, to answer your question, it's, we review the lost tones on a weekly and a monthly basis with the plant teams. We reinvigorated that process. I used to be monthly. Now they're got team meetings set up to review that data weekly. So, basically, what there are looking at, is last week, what causes production outage, and last month what causes production outage. What things and improvements can we put in place. Or what things can we do differently to stop that production outage from occurring again? So, that with the work that (name) and (name) who is gonna be my replacement in the new year. He is currently tied up with the (name) team. That's very much gonna be his drive, next year is loss accounting. This is gonna be more prominent within (site). Looking up why did that piece of equipment fail on what could have we done or improved to prevent that failure in the future.

I: So, well, coming almost to the end. Two questions left. If you take all those costs into account, what do you think are the particular advantages of a stand-alone reliability engineering department?

P: I think the beauty of a stand-alone entity is its independence. So, you've got the reliability engineers that talked about working in the planting team. They are very much a front line, and I've been that for thirteen years, it's not a pleasurable experience to have your day and your week destroyed by how the plants' performing. So, therefore from a central team perspective, I can step back and look at the problem with a bigger set of eyes rather and using a pair of binoculars to see the bigger picture. So, some of the decisions that I take, I know the plant teams aren't happy about it, it's a case of sort of working with the plant team to make sure that the bigger picture is improving safe tons at (site), you know. And all about instances where I should plant down. I'm gonna not happy with this. And said to the plant manager, right shut the plant down and he said to me: I have to get authority to do that. I said I'm giving you the authority. And the site director isn't happy with my decision. He will take that on me, you know. And I've got the power to shut the plant down and have done that. Not a pleasurable process, I must admit, because you have got to justify doing that with facts and data, but it's more about by having reliability as a central team. Condition monitoring and lubrication are two examples. We used to have that within the plant team, and that always fell off the radar because doing our lubrication and condition monitoring, when you got a plant in bits, is always something that gets dropped off

the radar. So, by having that within the central team and that was something else that I acted, lobby the site leadership team to get a dedicated resource whos (name) who is our condition monitoring technician and (name) who is our lubrication technician and that's within the central team. So, they understand, I protect that, so nothing stops them from doing their job. Within the plant team, that work couldn't be done. So, we monitoring lubrication and condition monitoring as a KPI to make sure they do their routines in that month. And they perform an eighty percent plus. So, 85 percent is the target I set them. (name) Ninety up percent, (name) she was 80 up percent. But is very much driven on whether that equipment can be made available for (name) so she can do the oil changes and stuff like that. So, that's, I think, that reliability engineering needs to be a two-tier event. You need to have that embedded within the plant team, but although you need to have that embedded within the central independent team as well, I think. Because otherwise, if you leave it within the plant team, those poor guys running around like headless chickens, just trying to get the plant back on line as quick as possible. And they will use whatever resource they got within the team to do that. So, it's a matter if you keep that asset ring-fenced, so condition monitoring, lubrication I've said, are two prime examples of that. Within the central team, then, at least you know, irrespective of hows the plants performing, that work will get done. And I've lost, I have lost count on because people say to me how much money he saved on reliability by doing lubrication and condition monitoring? Well, how condition monitoring equipment costs the business 30,000 pounds, right? I think we got the benefits back in probably the first months, that we are using that equipment and, you know, it's paying for itself. I've just spent 6,000 pounds on a new software update for our condition monitoring equipment, and the site leadership team didn't even bat an eyelid when I asked him for 6,000 pounds because we need to update our software. To make it compliant for the future standing. They know that 6,000 pounds if we can prevent one piece of equipment failure on our plant, which I'm sure we can and we have done. And that's money well invested and well spent. (name) recently got a new laptop. Because with working at home, it makes it a lot easier for him to analyze the data on the routes that he is analyzing from home. Unfortunately, it sounds like next week. (name) can be spending, probably, half of this week at home, analyzing data. And obviously, the other half was week, he's gonna have to be on plant taking the data. Because we haven't got a wire that is long enough to go from the equipment to his house.

I: Okay, and the last question is, would you like to add or elaborate on any of those questions before? So, you have the last word, that means.

P: No, I think reliability is very much a partnership, and one of my difficult problems is being/ I very much active as a (...) not, I wouldn't/ I take the information in. And some of the things I've been criticized for is simplifying the information and passing it on to the site leadership team and processing plant managers. So, sometimes I've been criticized for not telling the 100 percent of the truth, only selling 80 percent of the truth. But the object is to get the message across rather than battle people with detail. So, I

think the learning for all of these on all our sites is it's a partnership, but it's an education thing as well. We work with process engineers and line managers. Not people who understand reliability engineering in all its entirety. So, as long as we use data, we put that data in a format that can easily be communicated to all other work colleagues. Then I see that's been my major role. So, when I got the site leadership team wanting investment or wanting to shut the plant down to do stuff, I used that data. But what I do is I filter that data so I don't baffle them with science. I mean, without a problem with one of the Lawrence pumps with self-excitation at five times frequency. So, I've used slow-motion video and pictures. Because that paints 1,000 words, that kind of phrase, and I'm very much simplified the message, to get the message across rather than, well, it's on the vibration data. And then you gotta explain about Fourier transforms and frequencies and stuff like that. So, I filter that out. So, I'd probably a lot of my role is taking the data and putting it in a format that I can communicate that to (unintelligible, indistinct) process engineers novices, you know, the people who are not as experienced with reliability engineering. Because it's not their background. And the same with projects, you know, discussions I've in projects when we're looking at new assets, you know, so we're looking putting in new air compressors it, we putting new boilers in. And it is very much about communicating the message of reliability improvements with regards to new assets. So, spend a bit more on a piece of equipment to make that more reliable. And some of the things we put in recently, you know, like Warman pumps, oh we need some new Colemore pumps a Solemore pumps. So, we got a big project with Davenport cooling water pump at the moment. And that pump is out of manufacture. But I have managed to convince our project team to pay more, get the project manufactured in Brazil. Who still has the castings for that pump. So, it's identical to the pumps that we already have installed. So, that we don't have to buy turn-in spares, so we can reutilize the same spares. I don't have to write a new quality build plan for that pump. So, by spending the extra money on that capital project to get those pumps, sort of made specifically in Brazil, that saved us more money and did not have a spare pump. So, it's a full-time three-day-a-week job. I'm being a lot more relieved when (name) comes in Easter next year. And then hopefully I can, you know, I can hand over my role to him, so I can get more involved in, you know, I see my role move forward as more educating the graduated engineers that we've got for the next couple years rather than running around like a headless chicken.

I: Okay, so thank you very much!

8.7.9 Transcription Participant #8

Transcription

Participant No. 8

- Further information on the participant: See table in the appendix
- Date of recording: 02.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 26:39 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: So, the first question is: In which position do you work?

P: I am maintenance excellence manager for the UK.

I: And in which position did you work previously?

P: For (company) in the same role.

I: It was called the same?

P: What was a called? I can't remember what my role was called at (company), that's a good question. But, my subject was an expert for maintenance and reliability, let's say.

I: Okay, that's fine. And how long have you been concerned with the topic of reliability engineering in that context?

P: For ten years. I previously worked for (former company) in the same role as a principal advisor.

I: And how's your maintenance organization structure, and how is reliability engineering integrated there?

P: So, I'll speak for a single site because it's replicated across the whole organization. So, the way that the maintenance department is structured, we have at each site an engineering and maintenance manager. Below that, we have, what we call

maintenance team leaders, but you would call maintenance engineers. They lead the maintenance teams both from a maintenance point of view but also from a reliability point of view. So, each of the team leaders has allocated to them specific responsibilities. One of the team leaders would be work management. The other team leader will be reliability. That reliability maintenance team leader will be focused on, what we call reliability management. We have work streams similar to what we have with (former company). Which focuses on different aspects of the reliability management process, and that can be where we start with which is criticality of equipment. So, we understand what priorities are from an equipment point of view. We analyze the top losses on that critical equipment to understand exactly what failures are occurring and what we need to prioritize from a mitigation point of view and that can be through training of operators to operate the machines more efficiently. Understand what the (unintelligible, indistinct) of the operators to operate the machines, but also looking at the components on the machines and understanding why they failed and then conducting FMECA like we did when we were at (former company). Going through the process of understanding and what the components on the machine, what the lifecycle is, understanding what the failure rates are and what the failure modes are. Understanding what the impact is from a business point of view. Outputs and, from a reliability point of view, then what we do is we will as an output from the develop new preventive maintenance activities. So, we rank those in order like we did at (former company). And for those most critical components on the machine, will develop new preventive maintenance actions, or, and obviously, some things could be run to fail. But, we develop new preventive maintenance actions, we review those, and then implement them. What else do we do? Come back to the question, I lost track?

I: That doesn't matter. We were talking about the maintains organization in general and how reliability/

P: So, yeah, the maintenance team leader is responsible for that. There is a link into what we call the line-centric organization so, we have a specific role on the packaging machines where bottles and things are filled. Who focuses on what we call the technical stops. So there is an engineer who, well, on a daily basis analyze any technical failures which are occurring on the machines to understand the cause of failure and then recommend improvements either from preventive maintenance review where you know, because we're always looking to see whether the preventive maintenance activities are effective in preventing the failures from occurring. So, that person has a dotted line into the maintenance department. Within the maintenance department below the reliability team leader, we also have a preventive maintenance team, who specifically focus on the preventive maintenance activities. There ring-fenced, and their main focus is preventive maintains and on the focus on that.

I: And from your point of view, what shout the maintenance organization looks like, is it, well, you can say it's fine the way it is, or it should be different?

P: Some of the sites that we have within our organization don't have a ring-fenced preventive maintenance team, and you can see the difference between the ones that do have preventive maintenance organization and the ones that don't. The ones that don't have a preventive maintenance organization are very reactive there, focused on the day-to-day. Something's broken down, how can we stop that from breaking down, or will call a continuous improvement activity in. But, what they don't, there might be a tweak or fix a sensor on a conveyor, or something like that. It's not really thought through process and prioritization to be clear about how do we stop this breakdown from occurring again? It's very short term, is not long term, thinking about the life cycle of the machine. How's that machine worn out? Is it the end of its life cycle? Do we need to do line restoration activities? Another focus that we look at. Line restoration, bringing that machine back to the standard operation that required. Nothing like that! But, the site that we do focus on, with those proactive teams in place, that's the way it should look with the focus on the performance of the machines. Understanding what reliability looks like, what activities do we need to put in place to restore the machines back to their optimum efficiency and then allowing production to produce the targets which are set by the business. Or the outputs that are set by the business, that's what it should look like. Whether they have it, it is a different matter. I think it's very important that production and maintenance are one team. Or appear as one team together. If you work in silos, maintenance has their idea about what reliability looks like, and production has their idea about what reliability looks like, and if that is very opposed, if that is very opposite, then you very rarely see any improvement. When we got those two teams working together, reliability accelerates much, much quicker. So the clear understanding about what the end game is.

I: So, does your site already have a stand-alone reliability department? So, I understand, it doesn't have a reliability department.

P: It's not called, the thing is, it's not called a reliability department, but there is a huge focus on reliability. So, it's the role of the line teams who are autochthonous to focus on improving reliability. That is their main focus. There are targets within the business to improve OEE. Like I was saying before, within the OEE, the operating efficiency of the machine there are specific areas that we are focused on, which are technical stops, which are, why does the machine break down? Which components there are technical within the machine which are failing? And who is responsible to focus their activities on that. We call them the area engineers. The area engineers work with the maintenance team leader with the responsibility for reliability to eliminate or otherwise those failures from occurring. And when that all comes together, we can see huge improvements in reliability, for instance, and the site I'm working with down on (site) as a 16.82 increase in and reliability since February this year, which is huge from a business point of view. Because they implemented the right preventive maintenance activities. Establish the right regime from a reliability point of view, they've identified line restoration as a target improvement, and they train the operators to manage the machines in a way, in a reliability way. So, looking after the machines correctly.

I: So, you don't call it reliability engineering, but it, well, it actually is reliability engineering.

P: That's right, it is, yeah.

I: Okay, so, talking more generally, so not talking about your company. So what do you/ why do you think more and more companies are introducing a stand-alone reliability department?

P: I think, probably, because they look out of their business and look to see what other businesses, like, other food industry, from my point of view, all the food industry is doing to improve productivity, improve reliability, improve their way of working. Not just food industries, but what other industries doing. That can reduce costs, save money, and various other things like that. So, that is then an opportunity for them to look inwards and say we need to do something similar. We need to do the same. We are getting a lot of breakdowns. The company that I work for, when I joined two years ago, was very reactive, highly reactive in fact. It was losing money because of failure. And going over budget, from a maintenance budget point of view, because it was having to react very quickly to breakdowns which occur, and that, I think we know, I mean, you probably are aware of this, breakdowns can cost anywhere from three to five to seven times more than a planned job. And if we're having to stop production outside of maintenance windows, which was occurring within (company), then that means we lose the time for planned maintenance. But we also lose time because of a breakdown. So, instead of having once that maximizing that more of time that is available for a proper production point of view. Were actually minimization that. So, that's why we are focused on reliability. And I think that's why (former company) was. But I think when basically, it hits the fan, that's the first department that would normally go and think we've seen that, haven't we? In (former company) when we were there, it very quickly that department or that section of the maintenance department, because the very admin focused, very strategically focused, it's always the front-line engineers that remain in the into the day. But yes, I can see why, why we do that because it's reducing cost, reducing reactivity, maximizing the amount of time for production, and minimizing the amount of time for planned maintenance.

I: Are these although reasons, why you already have such a department? Even if it's not called so, or are there any other reasons for that?

P: That is the main reason, yeah, it's bringing value to the business, as I said before, so it's about value creation for the business, so, the shareholders can read the rewards at the end of the day. And one way to do that is by having a reliability department. So, our customers, how are the shops, can also have the product on time in full deliveries as well.

I: Okay, so, what types of improvements and savings do you expect from implementing and reliability engineering department? So, you mentioned a few, but maybe you can say it again.

P: Yeah, but this year we're looking to improve reliability by around, this is next year. So, in the business plan for 2022, we're looking to improve reliability between five and ten percent, more than we have right now. We're also looking to reduce the number of breakdowns on the machines between ten and twenty percent. And that is two different ways of looking at reliability there. Because the reliability more is focused on the length of time the machine is down, whereas the breakdowns of the count of the number of failures on the machines. So, it's a two prompt almost attack at improving the way you work. We're also looking to target improvements on preventive maintenance execution and drive that from 80 percent up to 90 percent a week in the maintenance schedule. Which is a huge challenge as well, because very often, production will cancel down days without, with very short notice. And so, that's another target for us next year, which is to work with our colleagues in the production department. The stakeholders within the organization to help them help create the vision of the reason why we need to be more effective and delivering maintenance activities to further improve reliability on the machines. So, the more proactive, proactive work that we do, the more efficient the machines become, the more reliable the machines become as well. And we got some targets also from an efficiency point of view in the maintenance department as well. So to try and reduce the amount of time it takes for us to do the work on the machine, so a more accurate about the length of time machine needs to be down for maintenance. Because I can go very often because we're not planning very well. We haven't all the spare parts we need to execute the work at the right time. And we didn't clearly understand the number of hours it would take to repair the machines or do a service on the machine, as well.

I: And have these improvements and savings been achieved in the past?

P: Yes, and it's all about sustainability at the end of the day. Normally, when we're implementing something, we implement though what we call maintenance boosts, so we'll spend six weeks on a site. We will look at all different aspects of maintenance. So, preventive maintenance we'll do FMECA, we'll look at actual failures on machines, will look at the way of working, will introduce things like escalation processes and troubleshooting guide for the operators. Or look at deep cleaning the machines and bringing them back to almost as new. That brings a lot of focus with it. From a maintenance point of view, but also from an operations point of view. And what we find is, that for probably three months following a proper boost. We will see a huge amount of improvement in reliability on the machine. And then everybody goes, few, we've done it, and then all of a sudden you stop, see the downturn again. So, sustaining is sometimes problematic, and I think when I was a (former site), we go back to (former company), here. We did a maintenance boost in 2000 and, must have been, 17 or 18, and we see a huge increase in the volume of pigment which was been taking or going

of site. And they went pew, and I think they spent all of the money on restoration, we spend a lot of time on FMECA, preventive maintenance, reliability, establishing ways of working, and within two years, everything started going downhill again. Because, they thought, I think the thought that line restoration had, was golden child, almost. And many, many sites think restoration, it gives you some breathing space, but what it doesn't do, is it doesn't give you the sustainability in the long term. We need to ensure that the activities that you implement, are going to take that machine to the end of its or towards the end of its life cycle and maintain it. Through that journey, and, yeah, that's key to success for me. And, I think, even sometimes people in my roll. Get, oh yeah, we finished that we've met our objectives. We move on to the next site, and then we look back, and we realize things are falling down. Because some of the activities that were implemented were not sustainable. Or people who have left the organization and the people who had the knowledge have left with that knowledge. So, it's very important that we got our processes, our guidelines, or principles. All the deliverables are all written down and available for the organization. That we're training continuously and coaching people to ensure that they are maintaining the standards which we expect

I: And how do you track the efficiency of reliability engineering?

P: How do we track the efficiency? Yeah, that's a good question.

I: KPIs, maybe, so, if you have any KPIs, you could name them.

P: So, we got overall equipment effectiveness. So, we used that, and that's measured every day and every shift. We got KPIs for specifically reliability within that. The targets range from fifty percent to 90 percent. So, some of our sites are very, very efficient from a reliability point of view. Others maintain it's very different from one site to another one depending on what the product is that comes out of the factory. Those factories, which are very automated, and have a lot of mechanical equipment, tend to be less efficient than others. Those factories which are producing powder, for instance, very similar to the pigment process, a lot more efficient than those which got a lot of mechanical components. So, we got KPIs for, quite a range of KPIs for everything, including the efficiency of people as well.

I: Okay, are there any other aspects you can use to see or measure the effectiveness of reliability engineering?

P: We got something called a breakdown tracker. I think we did have something like all we would look to implement at (former company). Where we count the number of failures on a specific machine, daily, weekly, and monthly. What we do is we target to reduce those failures. On a downward trend. And what we do is we look at the top three machines which are having repetitive, potentially repetitive failures and we work on eliminating or living with failures, depending on how critical the machine is.

I: Okay, now if you take all those costs into account. What do you think are the particular advantages of a stand-alone reliability engineering department?

P: From a cost point of view initially, it can be very costly in setting up a department like that. And I think that's one of the reasons why companies and sites tend to avoid it, because the initial reliability engineer, you know, could cost 100.000 Euros to have that role on site. To have specialists to sit underneath that reliability engineer, let's say you have two. That could be another 60 or 70.000 Euros. So, that initial setup costs can be high, once that's established, then we have resources which can focus on driving costs down. I worked in sites before where we have reduced the number of internal employees from 36 maintenance engineers or technicians, maintenance technicians within the department down to ten, and similar from a contractor point of view. 36 Contractors working on site, down to around about 10 because, because we are in control the machines are restored to their most operating efficiencies. And machines are not breaking down when they're not meant to. So, they're not breaking down during production. So, everything is controlled. We can have contractors on site specifically only for maintenance windows or services which are either annually or quarterly. The maintenance engine/, the maintenance technicians who are working in the departments only need to focus on planned activities. We hardly ever, we would hardly ever have a breakdown because we're in control. We have found, both all of them it or another company that I work for is that we need a lot of maintenance technicians because we got a lot of breakdowns. Very often, you'll hear an engineering manager say: Don't reduce my maintenance size, my maintenance department. I need more because I got lots of breakdowns. Well, actually, if we were looking to have reliability that we can reduce the size of our teams, reduce maintenance costs. How often does somebody have to go of site to a local supplier of components and buy them instead of, you know, because we don't have them in our storeroom, because we've run out, because we're overusing materials and then, of course, then pass another situation, that we have that we overstock things as well in the storeroom. So there's a lot of capital investment in the storeroom, which is just tied up waiting for machines to break down.

I: Okay, thank you, so, the last question: Would you like to add or elaborate on any of those questions?

P: I think, all our road down focus, rapid improvement, being less reactive, innovate, and being more productive. What are the things that I had in my mind. So, I wrote those few things done, proactivity innovation, less reactive, rapid improvement, and focus. And I think looking outside your own organization is really important because you can become so unfocused on how it works within your site or within your group that you forget that there are all the people within the world organization of business who have gone through this process before. And might be able to help you to rapidly improve, so, I think that sharing is very important.

I: Okay.

P: That's all, will that sufficiently?

I: Perfect! So, thank you very much.

8.7.10 Transcription Participant #9

Transcription

Participant No. 9

- Further information on the participant: See table in the appendix
- Date of recording: 08.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 19:31 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: So, the first question: In which position do you work?

P: I'm currently working as a reliability engineer for two areas here in (company). We are three reliability engineers, two of them are mechanical reliability engineers, and one of them concentrates on measurements and electrical parts as an engineer.

I: And in which positions have you worked before?

P: I've worked as a maintenance engineering manager in the service industry for chemical companies and specifically in the measurement for vibration analysis, parameter analysis for assets. And doing preventive maintenance plans and lubrications, and lubrication management for different companies.

I: And how long have you been concerned with the topic of reliability engineering, and in what context?

P: For seven years and in my studies, I've been relating, have been doing projects related to, not just reliability, but maintenance. And since I finished my master's degree, I've been working in maintenance and mainly maintenance. And the last drop as a reliability engineer, but I see vibration analysis, parameter analysis, lubrication is part of all that reliability or asset management centered maintenance as a construct.

I: And how is your maintenance organization structured, and how is reliability engineering integrated there?

P: We have a big in-house maintenance department. We have a, I don't know the word for Meister.

I: Foreman.

P: Foreman for each area, we have maintenance planning colleagues for each area as well. And having that big in-house maintenance department, we have all the know-how there, but we also use service companies to do several services for us. And the reliability department is integrated into the maintenance department, and we have three reliability engineers. And our focus was from the beginning mainly maintenance processes, but I've been working here for two years, and the focus had/ it's not just for the maintenance, but for the whole lifecycle of the machines, or asset lifecycle as you want to see it. So we work not just for the maintenance department but answer also questions for the quality department, production department, and a lot, we have a lot to do with the project department as well.

I: And from your point of view, you just explained how the reliability or maintenance department is structured now. What do you think what should it be?

P: We're integrated into the maintenance department. Can you repeat the question, please?

I: Yeah, you just explained how the maintenance organization is now structured on your plant. But, if you can choose, you can say, of course, that's fine's the organization is fine for the site, for the plant, but if you could change it. What would you say how should it look like for the plant?

P: It should be a stand-alone department. A reliability department, because all the Synergien (synergies), or departments we work together with, and the main focus is not just maintenance. We have to look further, or brighter, at what we can do with reliability projects and see the whole brighter view of what we can do. Not just for the maintenance of the machines, but the lifecycle of the machines and the cost we can reduce. Having that point of view of reliability-centered maintenance.

I: So, the next question will be: Does your site have already a stand-alone reliability engineering department? So, I understand there is a stand/ there is a reliability engineer department but within the maintenance organization. Is that right?

P: Exactly, exactly, exactly.

I: Okay, perfect.

P: And it has developed in the time, because we have now a lot of to do with continuous improvement and not just continuous improvement, in reli/ in maintenance, but in production or operations and projects and quality. So, it should

be a stand-alone department. Because the potential of the point of view not being in the day-to-day business in maintenance is essential to work with that potential and see the costs that can be reduced and how the processes, not just for maintenance or operations, but, as I said, all the lifecycle of the machine and you need to be standing alone, from my point of view.

I: Now, thinking about, well, not about your company, but companies in general. Why do you think more and more companies are introducing a stand-alone reliability engineering department?

P: I think it's very drawn on the new DIN ISO 55.000 because it's the asset management standards. And if your/ the main focus of that is that you look at the machine or an asset through all the lifecycle. And all the Schnittstellen (connections).

I: Connections.

P: All the connections you can have and you can have, and you can change in the lifecycle of a machine (...) I forgot the question that you asked.

I: Why more and more companies are introducing/

P: Ah, yeah, because in a lot of companies, they are looking forward to that reliability point of view. And not just for maintenance or operations, but in all the lifecycle.

I: And are these the same reasons why your company has a reliability department, or are there different reasons for that?

P: I think that's one of them, one of the reasons. I think they started in maintenance because we have a lot of potential in maintenance regarding costs and processes. But I think that we have done a good job in the last three years, and they have seen how much work we have to do with other departments. So, they see that the main goal is not just maintenance but the connections between the departments. So, I think in the future they will see more and more stand-alone opportunities of that department and make that as standard as well for the company. So, the first step they wanted to try, in maintenance, and I think they want to go further and long-term goals, to achieve long-term goals with this department as well.

I: Yeah, and what types of improvement and savings do you expect from implementing a reliability engineering department?

P: I cannot give you a number. I can give you numbers from single projects, but I think the main costs reducing goals are long-term. Because our goal is to see where are costs being produced. What are the bad actors in maintenance and in operations, why are the processes not working as effectively as they should be left or done? And so, I think you can tell specifically in five, six years what the construct of reliability having change

processes in the company can be shown. But in single projects, for example, we have four gearboxes. From a maintenance point of view, we should have ordered two gearboxes. And with the work of three weeks, we, reliability engineering, saw how we could change the gearboxes and save roundabout 300.000 euros just by purchasing not two gearboxes, but one gearbox that can be used on both sides. This is just one of the projects that, in one year, saving 300.000 euros is a lot of money. But that's just one point of view. On the other hand, for example, we have been saving energy in a vacuum pump, for example, that's a project of a colleague of mine. That, the standard point of view, the electrical part says, is the pump that's making problems. The electrical department says it's, no, the mechanical department says the motor that is not running okay. And the reliability department says, let's look at a bigger point of view. We sat all together and then, the result of that project was, that the pump, the inside of the pump, has to be overhauled and there expecting energy savings and in one pump from 60.000 euros a year. From one pump! And we're talking, we have eight or nine pumps up those. So, it's very difficult to see where the savings could be going because the focus of the mai/ of reliability job is so bright that you can do energy-saving, spare parts savings, process optimization, or making those effective and changing an asset or technical place. Because you saw that, I don't know, the pump was not dimensioned, no, calculated, as it should be, and then you're saving a lot of money. But that cause or that numbers you will not see them directly, somewhere.

I: And, well, the next question will be: Have those improvements or savings you were expected archived in the past, but you already said you just started three years ago, so you're not sure about that. Is that right?

P: Yeah, I'm not sure about how many saving, but you can say that what we make as a person, as an engineer, we are saving more than that. So, we're paying our role in the company.

I: And how do you track the efficiency of the reliability engineering department? Are there any key performance indicators, for example? So far?

P: Yes, yes we track a lot of the work orders that we see daily, daily basis. So, one way we track those is that we take care of bad actors, for example, why we have many bad actors. For example, with emergency work orders and how high is the percentage of emergency work orders and then reduce those emergency work orders to a zero for a technical place and then start with the next one. Those that can be your number, but that's mainly maintenance focused, and on the other hand, also maintenance focus mean time between failure, the cost we are saving, for example, for oils, we're putting together different, we have, for example, 20 different oils and we're putting time into what should be ordered in oil and the amount of oil, and now we reduce it to five, for example. So, those costs were tracked as well, but we don't have a KPI just for reliability. We used the KPIs that use operations like OEE or maintenance on a daily basis.

I: Are there maybe other aspects you can use to measure the effectiveness, like reduction in the production losses, for example, or reduction in mean time between failures. Are there any numbers you are getting on a regular basis?

P: We're not getting them. We are trying to track them. That's one of the main issues about reliability. We three reliability engineers because they want to see KPIs, but it's difficult to put it into KPIs. Because it's always regarded to an asset or to a machine or to a cost that we reduce. But, that's a good question. How can you track those numbers just for reliability? In all the aspects you work on as a reliability engineer. We look at single projects that we are working on and on the costs that we are saving. That's the main point. For example, on rolling stations, we had the lifetime of a rolling station, was, when I arrived, about six months. And we took that issue, rolling station for a kill, and we started a project to see what can we change in the oil system? The cooling of the oil and the mechanical parts. And we expect now to have a lifetime of the rolling station of two years minimum. So, that's, for example, how you can track that in a long time, but not right now.

I: I understand. So, the biggest question is: If you take all those costs into account, costs from a reliability engineering department, what do you think are the particular advantages of a stand-alone reliability engineering department?

P: To try things out. To have, to think out of the box. To not accept the answer: We have done that forever. And to see what possibilities are on the market. How the market on reliability, on maintenance, and technologies have evolved, and what opportunities you can have. Trying things out. Have the guts to say: Let's do a project out of this, let's invest some money and, for example, I don't know. Take a measurement on a specific point just to see how the temperature of the kiln is in that area. Because you have, you think that you have a hint on what can be an influence on a parameter and to just try out, and, how to say that, to try out things.

I: Okay, and the last question is: Would you like to add or elaborate on any of those questions? So, you have to last word, that means.

P: I think that reliability engineering, reliability-centered maintenance is a huge topic that will be confronted in so many departments of so many companies. Because the lifecycle aspect of an asset or a lifecycle point of view and way of working with an asset is essential to work reliably. And a stand-alone issue from the reliability department is essential, and having a budget to try things out. New technologies and anything. Here specifically in Germany, where processes are already very standard, and processes have not be evolved for many years. It's a new wind and new approaches to disrupt that processes and see what can be done better. And, I think reliability engineering, a reliability point of view for assets, is essential there.

I: Okay, so, thank you very much.

8.7.11 Transcription Participant #10

Transcription

Participant No. 10

- Further information on the participant: See table in the appendix
- Date of recording: 24.11.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 19:53 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: The first question is: In which position do you work?

P: Currently, I'm the production manager of the (site) and responsible for the black end of TiO₂, the acid recycling plant, and the sulfuric acid plant. Previously, I have been working eight and a half years in a comparable position at the (former site).

I: And how long have you been concerned with the topic of reliability engineering in that context?

P: In that context, I would say since 2015. However, since I became plant manager and in 2003, the topic of reliability has always been a vital part of my daily business.

I: And how is your maintenance organization, so it means the maintenance organization on your site, structured and how and how is reliability engineering integrated there?

P: We have a centralized maintenance organization, this maintenance organization, and this is pretty much what it is at (former site) has decentralized asset managers. These asset managers are accountable for a certain plant, and these asset managers are accountable for the condition of the assets. The reliability issues are, let say, discovered or indicated in the daily business it is decided whether if it is a reliability issue, and this reliability issue is then handed or forwarded to the technical department when it is more comprehensive.

I: And those also reliability engineers or specialists or technicians do they report to the asset managers or to whom do the report?

P: The people who are in the technical department report to the SLT-member who is accountable for the technical department, the ones who are working in the maintenance organization report to the SLT-manager accountable for maintenance.

I: And from your point of view, what should a maintenance organization in regards to reliability engineering be?

P: It should be, first of all, a team. A team that sees its global accountability in preserving and improving the assets we need for production. I'm not a big fan of black and white.

(The interview was disrupted for a short telephone conversation of the participant.)

P: Okay, well, I see it as a team. I see it as accountability to provide assets, it's always a collaboration with the production guys because they notice the things that do not work because they're running the assets twenty-four/seven. On the other hand, it is an organization within the maintenance and reliability team. And this organization has to follow individual skills, who is the best person to tackle a subject, and it has to follow a joint strategy, meaning that it is our aim to improve the reliability of the assets together. This is the global strategy and the global vision of the team.

I: Thank you. You've explained something about the reliability or maintenance organization so far, but is it a stand-alone reliability department, or are those reliability specialists assigned to the different plants. Are they together in one department, or are they split up into a lot of departments?

P: At the end of the day, they are split, but they work under the umbrella of one SLT-member. I think that it is important that there is a certain interchange and that they exchange their views and exchange their experiences. If they find something interesting in part A, they have to make sure that they transfer this knowledge to part B or part C. Sometimes it can be done; sometimes it cannot.

I: Thank you so, talking not about your company, but about companies in general. Why do you think more and more companies are introducing a stand-alone reliability engineering department?

P: Well, at the end of the day, we have to ask these companies. It's a strategic thing. The difficulty in the reliability teams that follow different routes or that are embedded into a maintenance organization is that their time is eaten up by the daily business. This is a permanent thread so that reliability topics that have an impact in let's say, six months or a year, take longer to execute are eaten up by the daily business and challenges we have in a running week. To my understanding, this is a strategic

decision to make sure that the proper reliability projects are executed and that the resources are dedicated and remain dedicated.

I: Is this the same reason why there's a reliability engineering department at your site, or are there other reasons for that?

P: I think it is a comparable reason it's also a combination of skills. The skillset of a reliability person is sometimes different than the one of a maintenance person and also the mindset. The mindset of maintenance guy has to be: how do I help the plant, how do I get this fixed? Sometimes it is "Oh my god, I have to repair this pump for the fifth time, but there's no way around it. I will do it today". While the procedure of wise philosophy of reliability, this has to be: "There is room for improvement. I will think about it and implement something different". I think that it's tricky to mix these two completely because sometimes their skills and their daily business are different.

I: Thank you. The next block of questions is about expecting savings through a reliability engineering department. The first question is: What types of improvements and savings do you expect from implementing a reliability engineering department?

P: The huge portion of savings is, to my understanding, driven by production output and plant performance. And all these savings that come along with a stable plant performance are energy savings, raw material saving, and, first of all, a planned output, good plant performance, and a stable turnover, and this is, in most cases, the biggest saving. Of course, if the plant runs stable without interruption, its efficiency, its yield, its energy compassion, and often also the planned maintenance and unplanned maintenance is reduced.

I: Can you quantify these expected improvements and savings, for example, in the percentage of reduction in the maintenance budget or reduction in loss of production?

P: If we talk about the loss of production, it's difficult. But we know based on the turnover, even a saving of one or two percent or an increase of one or two percent is huge! A huge lever, and therefore even a challenge or goal of three percent, is a huge goal and a big portion of sayings.

I: And have these expected improvements and savings been achieved in the past through the reliability engineering department?

P: I think we have achieved savings. I cannot comment on the current situation in (site), I can only comment on the (former site) situation. We have struggled with a crystal clear definition of what savings are driven by whom. Sometimes it has been an issue of CAPEX; sometimes it has been an issue of operator absenteeism; sometimes it has been an issue of raw material availability. So, we are working on a loss accounting concept that allows us to clearly define which savings are generated by whom. But for

the time being, there are still certain uncertainties about what is really, really, really the impact of this project.

I: Okay, I understand. The next few questions are about evaluating the effectiveness of a reliability engineering department. How do you track the efficiency of the reliability engineering department? Do you have certain KPIs, for example?

P: Again, my current commend is based on the (former site) team. Yes, there are steering committees. Yes, there is a list of projects. This list of projects is re-visited, and priorities are defined. If we agree on a project, we can track it. We have a timescale, and we can track whether this project has been executed on time. Then we have a follow-up of this project to see has it been executed and do we see the impact.

I: Are there any other aspects to measure the effectiveness, for example, meantime between failure or other things?

P: Yes, we try to evaluate plant performance on a weekly basis. What are the interruptions, which interruptions can be dedicated to a reliability issue, or is there something else that has to be taken into account? For example, if we have simply absenteeism of operators and we lose tons because we are understaffed or something like that. We cannot really, let's say, dedicate this to the reliability team. If it is dedicated to reliability, we have to see whether this is a new subject because we cannot blame a reliability team for a new subject. If it has been there before and we see it again, we have to take a deep dive, and we have to discuss why this measure and why this project has not been as effective as we thought it could be. KPIs mainly refer to the questions if the project has been executed on time. My personal estimate is if we check the long time effectiveness of measures, we don't have clear KPI's. We often do it by daily business experience and feedback.

I: Thank you. If you take all those costs into account, what do you think is the particular advantage of a stand-alone reliability engineering department?

P: The advantage is to me that, first of all, a project can be driven because the resources are not eaten up by other departments.

I: Sorry, improved projects you're talking about?

P: Yes, we can prioritize, and then we can really dedicate these resources to the projects we want. And the advantage is that separate this from the daily business. In maintenance, it is unfortunately often the case that the challenge supersedes the weekly planning. Of course, you could say this is a reliability issue, but for the time being, it is what it is. In the reliability team, a decentralized central reliability team, I would expect that priorities are a great problem. And if a new project is not introduced, I would expect that the other project that has been agreed follows the time plan. So it's a project organization while depending on the situation in the maintenance

organization, has to react to new impacts or to new developments much quicker. Even if we would love it not to do so.

I: Thank you, coming almost to the end. Would you like to at or elaborate on any of these questions? Anything about reliability engineering you would like to at?

P: Well, two or three concluding remarks. I think reliability is important, and I would say that dedicating resources to reliability pays off. Not on day one, but let's say, on the longer scales, long timescales, you will get payback. It is important to integrate reliability, it is a compromise between separating the project and make sure the resources are not eaten up and integrating reliability to the daily business. We have to avoid an ivory tower where reliability guys work on their projects. They have to see themselves as a support of the plant, and the plant has to see them as a support. This is the key to collaboration. Make sure that the information flow is generated and that it is really a team and not a separate organization.

I: Okay, thank you very much.

8.7.12 Transcription Participant #11

Transcription

Participant No. 11

- Further information on the participant: See table in the appendix
- Date of recording: 08.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 17:34 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: First question: In what position do you work?

P: I work as a director of maintenance and engineering. So, I'm responsible for all the CAPEX-projects here at the site, as well as for maintenance works which consist of an own workshop, but also for the maintenance, the engineering and the reliability teams.

I: In what positions did you work before?

P: In comparable positions as head of maintenance and engineering or as a technical manager of a site. So, the same content, different sizes of teams. Or responsibility for two sites, but very comparable.

I: And how long have you been concerned with the topic of reliability engineering in that context?

P: I would say I started in 1998 in the industry, and even at that point of time, that was an issue. It was not called reliability but the issue or the aim of not only doing a one-by-one repair. But trying to improve the assets, trying to improve the equipment by using of advanced materials or different design to get longer run times, higher availability. That was even at that point of time so more than twenty years ago it was still an issue. It was not so structured and so well defined as it is today when we talk today about reliability.

I: Okay, thank you. And how is the maintenance organization on your site structure in regard to reliability Engineering?

P: Currently, we have two reliability engineers which are doing 100 percent reliability and have also the label of being a reliability engineer. And they are supporting all the plans at the site here. And in addition to that, there's also a lot of reliability thinking and methodology in the heads of the maintenance engineers and the workshop leaders, and so that reliability is more a cross-functional aim than being only located in these two persons.

I: Thank you. From your personal view, is this maintenance organization a good organization, or should it be different, especially with regard to reliability engineering?

P: Yeah, I think there's, on the one hand, it's helpful to have their dedicated reliability engineers which are focusing on the methodology of implementing new technologies like pushing the condition monitoring, or we have projects here with KI or AI, artificial intelligence, to identify large data amounts and derived from that the status information about the processes and so on. That is something definitely, it helps to have dedicated people for such jobs and projects. On the other hand, some of the plant engineers, there is still an attitude of "I keep the plant running, it doesn't matter how I do that. And when I do it, when I'm very fast in a one by one replacement that's also fine and the reliability, that is something of the reliability engineers." And there are strongly working to get this old mindset, to get rid of this old mindset. And I tell my people, every plant engineer: You are also the reliability manager of your area, and you can ask the reliability engineers to support you, to help you to implement new methodologies. But you are responsible for the reliability of your plan, and that's not the responsibility of some central functions.

I: I would like to come back to the question before, so you said you have currently two reliability engineers doing 100 percent of reliability work, to whom do they report? Directly to the maintenance manager?

P: No, they report to me.

I: All right.

P: To myself. So, it's, they were positioned directly as a direct report of myself, to keep this reliability engineering as something which is very strong in the focus of the technical management.

I: Okay, thank you. So, the next block of questions is: Reasons why companies want to implement reliability engineering departments. Yeah, you partly answer this question already. Does your site have already a stand-alone reliability engineering department which you said: Yes, you have two people doing 100 percent reliability work.

P: Exactly, that's right.

I: So, talking about different companies. So not your own company. What do you think, why do more and more companies are introducing a stand-alone reliability engineering department, especially in the last ten years there more and more companies which introduce a stand-alone department for reliability engineering?

P: I think the costs, the target to reduce costs and to increase the availability of plans is increasing year by year. And in order to achieve their progress in this direction, I think it makes a lot of sense to have it not fully implemented in the day to day business of plant engineers, and therefore I think it makes sense to have dedicated teams or dedicated people who are fully concentrated and who are fully aware about the reliability methodology, the new technologies, and act as a kind of center of excellence concerning reliability for a site or for a company.

I: Are these the same reasons why you have a reliability department on your site?

P: Yeah, that definitely. They are doing the pilot, they are doing the testing of new methodologies, and then it's rolled out in the broader maintenance community here at the site.

I: So, let's talk about savings. So, what types of improvement and savings do you expect from implementing a reliability engineering department?

P: Yeah, that's a little bit difficult to answer, because of course, that's mixed with the whole maintenance effort. I personally think it's not possible to dedicate it to such a department, the savings. But in general, my expectation is that due to reliability works, due to reliability improvements that we are continuously working on, compensating the inflation we have. And furthermore gaining a reduction of about two to three percent of our maintenance cost to drive that down.

I: So, you partly answered the next question. So, how can you quantify these expectations and improvements, so in percentage of maintenance budget or in cost savings or in what else you can say, cost cuttings or something, can you put it in some numbers?

P: Yes, our target or our expectation is not to increase the maintenance budgets, which is the first step. That means we compensate the inflation by higher efficiency and the second one is to reduce it year by year, of about two to three percent. And this is then, of course, absolutely the direction we want to go and here for our site that means its range of 300.000 - 400.000 dollars per year, reduced budgets.

I: Have those improvements or savings been achieved in the past, the past years?

P: The last two years, we were able to achieve that.

I: Perfect. So, the next block of questions: Evaluating the effectiveness of reliability engineering. And that's, the main question is: How do you track the efficiency of your reliability engineering department?

P: We have a set of global KPIs which are company-wide defined, but for example: How do we conduct our preventive maintenance tasks, are they conducted in time? That is the amount of risk assessments which are conducted. To rank the equipment in certain risk classes and deriving maintenance and inspection plans in relation to the risk amounts related to the assets or the equipments. Furthermore, we are tracking the downtime of equipment. So, OEE as a KPI here, and thereby, of course, we track how reliable our equipment is.

I: Okay, thank you. Are there any other aspects you can use to see the measurement of effectiveness? So, for example: If you are able to reduce the production loss or something like that?

P: Yes, that is covered here at our site with the downtime. So, we exclude in the downtime KPI equipment which is not demanded for production. So, when we say there's a downtime, it means also it has an impact on production loss. So that's linked here in our set of KPIs. And it's not only production loss, it's also quality. We are also tracking what is out of spec and is that out of spec might be a reason for a pure maintenance work so that was also not reliable.

I: Thank you. So, coming almost to the end. But the biggest question is: If you take all the costs into account, costs for personnel and so on. What do you think are the particular advantages of a stand-alone reliability department?

P: I think the advantage is, that you avoid the danger that people are more concentrating on day-to-day tasks and thereby losing the focus for mid and long-term reliability improvements. Let me give an example. When you are doing vibration measurement which most of the companies who are doing reliability work are doing vibration measurements. If you are just focussing on conducting this vibration measurement, you might lose the topic, how can we improve that? And having this stand-alone reliability team, we are focussing on transforming from this rounds where people work around and do the vibration measurements to transform that to an online vibration measurement. And that is this strategic element that improves on a long term basis the reliability of the plant. I personally think that can be better improved by having a stand-alone reliability team instead of just doing it with the workshops or with the plant engineers. But, I think it's also important to have also this reliability mindset at the plant engineers. So, I personally also like to have job rotation between these two functions. So, that both are aware, so, having only a reliability engineer who's not caring about the day to day business and who is not caring about what's happening in the plant. That would be, in my eyes, not a good reliability engineer. So,

there has to be a very close interaction and linkage between this central reliability team and the plant engineering teams.

I: Thank you. So, the last question is: Would you like to add or elaborate on any of those questions before?

P: I think I have captured everything. Maybe the only aspect that I see, often when we are focussing on reliability, we are focussing on mechanical equipment and mechanical reliability. What I see or what I think what has to happen in the next years and there are further improvement is also to focus on the reliability of E&I equipment, on DCS system and so on. Because with an increased level of automation, if there is an error or an outage on the electronic site, on the E&I side, the impact is even or maybe sometimes even more dangerous to the performance of the plant than the pure mechanical defect. So, that might be that the profile for reliability engineer or the team qualifications might be a little bit different here at my site. One of the reliability engineers has a mechanical process engineering background, but the others have an E&I background, and that is, in my eyes, that it is an advantage and that helps us a lot that we could investigate or improve reliability in a more comprehensive way and not only looking at the mechanical site.

I: Okay, thank you very much.

8.7.13 Transcription Participant #12

Transcription

Participant No. 12

- Further information on the participant: See table in the appendix
- Date of recording: 09.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 19:42 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: So, the first question is: In which position do your work?

P: I'm the reliability manager of the plant in the maintenance department.

I: And in which positions have you worked previously?

P: I've been working as plant manager in the black end, as a process technologist in the black end, as an area engineering manager in the white end of my plant. And the technical office in the technical area also as a process engineer. More or less, this is my background in this company. I was working as chief of technical office, project engineer in another company.

I: And how long have you been concerned with the topic of reliability engineering, and in what context?

P: I have been working from 2015 as reliability manager and anywhere in my last position as plant manager and as a process engineer, I was involved a lot in different improvements, in different analyzes of problems related to reliability from the production part, and helping the maintenance people to solve the issues.

I: And, well, how is your maintenance organization structured? So, who reports to whom, and where is reliability engineering integrated there?

P: Okay, we have a big department of maintenance. This is the first, and then we have/ the plant is divided into three areas of production. This is the black end, grey end, and

white end. In each of the areas is a project/ an area engineer and a planner, maintenance planner, and one for contractors as well. And besides this organization that is mainly for day-to-day or planning maintenance, but not related to the day-to-day work of maintenance. This is also a reliability department this is, kind of, for the help to do new projects for the improvement of the plant and also to collaborate with the technical office, engineering department for new projects. We have there our analyst part parallel to others, depending on the manager, maintenance manager. And then there is another department of electrical engineering and control. And also another part of these workshops, of these mechanical workshops, coating, rubber, lead, and other specialties. That is, more or less, this is the structure of the maintenance department.

I: And, well, you just explained how the maintenance department looks like, but if you could change it. Do you think it's a good organization for your site, or would you do it differently?

P: Well, I think it's okay. It goes this some people more oriented to the day-to-day job, to the day-to-day problems and (unintelligible, indistinct) and so on. And other people helping there improve the results, trying to develop all the improvements, helping RCA and problems that arrive continuously. Also, in the department of reliability, we have, of course, predictive maintenance, that vibration, infrared, thickness measurement, and other methods. So, I think is, from my point of view, is good, is good enough to have this kind of separate people in the department.

I: But the reliability engineering itself, it's a separate department within the maintenance, is that correct?

P: It is inside maintenance but depends on the maintenance manager also. But it is separate from the different parts. We work together, we, of course, are involved with a lot of things with them. But it's not depending on the area engineer of one area. This is, in fact, our own department. With the various engineers, we have three engineers and one is for predictive maintenance and the operator for predictive maintenance, and me. So, we have four engineers and one operator for us.

I: And, well, if you think not on your company, but on companies in general. Why do you think more and more companies are introducing a stand-alone reliability engineering department?

P: Well, I think it's a very good tool, it's a very good strategy to improve the reliability of all the plant—our plant, what we have before before I came to this department. And there was a lack of analyzing of the problems, try to study what is happening, try to improve, for example, every time you make a CAPEX, should recover all the experience of the people who are with these problems, not forget this and take a machine that is not well approved for the rest. So, these are a lot of the things that the reliability department gives to the maintenance general, production, and so on. I think

it is very important to have this. I think (name) in the general direction is quite happy with the focus on the behavior of how we are working with the vibration of the plant and doing the improvement projects and so on. I can say that.

I: And are these the same reasons why do you have a reliability engineering department on your site? Or are there any other reasons for that.?

P: Sorry, can you repeat the question?

I: So, the question was: Are these same reasons why you have a reliability engineering at your site, or are there any other reasons why you, on your site, have a reliability engineering?

P: Well, I think it's quite an interesting job. I think it is quite creative, also requires knowledge of the production part of the plant. It is, I think, quite difficult in some cases, do have not the knowledge and the language and so on of the production part to make really good improvement, a good group working together to solve this. I like this kind of job because it is at, in some cases complicated things obliged you to think a lot around the problems, I think is creative, is good is/ we are (unintelligible, indistinct) every day working to file trial. I think it is a very good (unintelligible, indistinct) these for me.

I: And what types of improvements do expect from a reliability engineering department? Improvements and savings?

P: Okay, we are working, we have, for example, every year we make with the, all the production areas and the area engineers we make a list of projects we should work in order to improve the performance. Sometimes, it is tackling bottlenecks; in some cases, are more bottlenecks and something to happen. And in another case is related to cost, maintenance costs. The case is also EHC control. What we are is making now a list of projects that could be for projects where you make some modifications. In some cases, you have to study what is happening in the machine and so on with or without major, or major changes. Maybe changing trips, alarms, or changes in the process in general. We have a group of people deciding, we made in the past some FMEAs, and these are very, very, very good tools. I think, through a study of sections, in particular, that has many, many problems. The invention of (unintelligible, indistinct) production and site to improve making a systematic approach for the analysis, no. We made for digesters; for example, we made for reduction, we made for the (unintelligible, indistinct) plant. And then we made a list of a huge amount of different actions to make this, so. This is the best systematic approach I recommend to follow.

I: And can you quantify the expected improvements and savings? So, for example, you want to reduce the maintenance budget by two percent per year or to decrease production losses by five percent per year. Can you say anything in numbers about your goals in reliability?

P: There is an example, we in the, for example, in the FMEA we made for the digestion section we reduced the amount of losses related to this section in 2016 to 2018, more or less, in two and a half years or something like that thirty percent. All in this area, because we had problems with (unintelligible, indistinct) of the digestion with the type of nozzle we have. We have problems with the injection nozzle, lateral injection nozzle, with the valve of the (unintelligible, indistinct) with the T that is in the bottom. With the material reductional and the (unintelligible, indistinct) with the lead or so. We made a lot of improvements was in about two, two and a half, 2.5 years and we have seen a very, very good improvement, for example in this part. Not (unintelligible, indistinct) not so clear, but also, for example, in the sludge pump in the same to the rotary filters, we had a lot huge problem there. We have testing now, so, in precipitation similar, but another material. So, we had made other changes, that is, I think, have been very, very good for the plant, regarding production, regarding uptime, regarding maintenance costs.

I: You definitely have achieved improvements and savings you can prove?

P: Yeah, yeah, we can prove absolutely! We can have, we have a big, very big (unintelligible, indistinct). With the (unintelligible, indistinct) we made (unintelligible, indistinct), and we have a follow-up by the manager, the site manager (name). Every month we review, the advance, we review all the projects that go wrong from delays or something like that. And we make an estimation of improvement of the different parts. And we try to make an estimation of the savings that we have achieved.

I: And this is a way you track the efficiency of reliability engineering?

P: Yeah, this is a part, well, we have a list of targets in the year and also not only in preventive, but also we manage the legal compliance of pressure test or inspection and so on. So, we have different tracking or charts to follow up on these parameters. We informing is there is only delaying the repairs if the documentation is good archived. So, we have different notices. But again, these a ways we, I think, we follow up different types of all the departments. We also have we follow up oil and grease of the machines and the vibration routes also. Follow up these machines which is too much time with offside, of spec of vibration. So, we have different follow up, which is, more or less, the way we track.

I: Do you use any KPIs, standard KPIs, to track reliability engineering?

P: Yeah, we have these, well, it is not a standard one, but is the tracking of the with inform, maybe one, the work order is closed or complete (unintelligible, indistinct). And also, we have a KPI, for example, for the completion of the maintenance, planned maintenance of critical equipment, we have a list of critical equipment. And we follow these plans because this, we have this tracking but in the day-to-day, the plans of the areas that make the execution of the maintenance but which chart they are following

and this a problem, we inform what if this is or not. And in general, we make some KPIs for this kind of work. But is not very defined. But we have a kind of mean time between failures for the different areas and the planned maintenance of critical equipment. For the moment, we are only following up on the critical equipment. Not more, for the future maybe.

I: Are there any other aspects as well, so in, well, less breakdowns or more availability of the maintenance people anything like that, you tracking?

P: There are other people that track this part of this person for the (unintelligible, indistinct) operator, the number of standard procedures we apply. We are participating in some of them. But not all of them. Because we try when the people come to work, two mechanics or one called to do a job. In many cases, this is kind of standardized, no. And we measure the amount of the job, but this is made to using a standard procedure. We are continuously trying to make/ in our department we don't make too much. We are participating in some special ones, big ones, calciners and so on and the workshops. We have also started to follow the quality of the jobs in the workshops of the (unintelligible, indistinct). There are people who also track the amount of standards procedures and work to try it to increase. Sorry?

I: Yeah, so, I don't see your picture anymore, but I can hear you, yeah.

P: Sorry, but sometimes I have a problem with the connection.

I: Yeah, but, well, as long as I can understand you, everything is fine.

P: Okay, more or less, is of the kind, but we don't track all of them. All of the variables, of the KPIs. But there are some KPIs like completion of the legal inspections, completion of the critical equipment in maintenance. Something like that and different completion of the projects, of the different improvement projects.

I: And, so, two questions left. Now, a reliability engineering department costs a lot of money, of course. And if you take all those costs into account. What do you think are the particular advantages of a reliability engineering department?

P: Well, I think is, we can see we are improving around the plant. We can see our plan, which is the consistency of the production, of the uptime of the different sections. And a clear cost of production, for example, in some type to justified clearly. And in general, I think the plan is quite clear with the results of the job, I think. In fact, we have, the department starts with me only. And now we are three engineers. We quite have.

I: Yeah, so, and the last question is. Would you like?

P: (unintelligible, indistinct)

I: Say again.

P: Si, yeah.

I: Okay, yeah, so, the last question is: Would you like to add or elaborate on any of those questions? So, you have the last word, so to say.

P: I think it is very good to have, I think, for all our plants, to have a reliability department. With people very involved in the knowledge of the plant and the maintenance and production part. And I think it is a key part of all the site chemical or other facility. And I will recommend a lot to any kind of industry to have this kind of people, this kind of department working for the improvement of the reliability of the plant. I think it is the future.

I: Okay, so, thank you very much.

8.7.14 Transcription Participant #13

Transcription

Participant No. 13

- Further information on the participant: See table in the appendix
- Date of recording: 06.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 13:53 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: First question: In which position do you work?

P: Head of engineering.

I: In which positions were you previously employed?

P: Various those, from global reliability manager. I have been a change consultant within reliability engineering or asset management, as it's sometimes called. And I've also been an engineering manager for a site as well, or maintenance manager, as is sometimes called. All of which focus on reliability in some context.

I: And how long have you been concerned with the topic of reliability engineering in that context?

P: I would say twenty years in various different roles, different industries, and different levels of maturity. It would be twenty years in total.

I: And how is your maintenance organization structured, and how is reliability engineering integrated there. If you can say it in simple terms.

P: Okay, we have sixteen sites. Every site is different. Reliability is not well featured in our culture at the moment. We don't have a set of free people. We don't have reliability roles within our sites yet. So, on the cultural change to try put in those roles. So, historically our business, (company), as been for everybody onto a shift. And that's one thing to failure. On the shift teams, they do reactive work and fix problems. We

now trying/ part of my role, which is new, is to try to change that culture and bring in a reliability function. So, I've managed to get three sites so far to put in a reliability engineer role in (unintelligible, indistinct) of the headcount, and we are in the process of recruiting for those at the moment.

I: And from your personal point of view, you just explained the structure as it is and what do you think it should be.

P: To me, every site should have a reliability function that's independent of the day-to-day maintenance. That will work on long-term and short-term improvements to analyze data managed by fact and put in place improvements for the site.

I: So, the next question, but I think you have answered that partly. Does your company, site already have a stand-alone reliability engineering department? But I think you have answered that already. Well, you said you would like to have an engineer/reliability engineering department on every site. What do you think when do you start building that?

P: Starting now, and we'll focus on the sites that need it first. And it will progress well into next year, so I would say, all the next year, year and a half, we will drive the put-in those roles. We got approval for three I need to demonstrate the benefits of those in order to get the rest.

I: Understand, so if you think on companies in general, so not the company your work for, companies in general. What do you think are the reasons why more and more companies are introducing a stand-alone reliability engineering department?

P: Simply because, regardless of the company you are in, regardless of the country you're working, our assets have been underinvested for many, many, many years. We ask them to do things that weren't designed to do. The capital has been reduced, there is a large number of assets that are unclear where to prioritize, to reduce the costs, and improve the reliability at the same time. So, I would say that's why companies are looking to be involved to manage all the assets, understand the risks, reduce cost at the same time as ensuring reliability and safety.

I: And are these also the reasons why you already introduced a reliability engineering department or intended to do so?

P: Yes, absolutely. In addition to that, we don't have data to drive the main decisions at the moment. We don't have a CMS, a common CMS, or SAP across all sites. Seven of our sites have some good Mainsaver. The rest use Excel, Powerpoint, Microsoft Word. We need somebody in there to standardize common processes, as well, as, and then the benefits will come after that.

I: Yeah, yeah. So, what types of improvements and savings do you expect from implementing a reliability engineering department in detail?

P: So, I think that depends on what level you picture us. Up the high level that interested in a reduction in maintenance spend and improvements through OEE, improvements coming through a reduction in loss. I think at a more detailed level are expect to see equipment-specific improvements in the mean time to failure and unplanned downtime per asset. And also, we have people surveys every year. Most companies I worked in have done people survey to get people's feedback. All of the feedback we get, from an engineering point of view, is that we are backwards and behind the times. I want to improve engagement scores to keep people retained within the business. This is a difficult out there of COVID, people taking a step back, and they looking of all opportunities out there. I think more companies in the food industry are struggling to retain people. There is so much competition out there, so we need to be seen as giving people the best we can, the best tools we can, to retain people as well.

I: And can you quantify these expected improvements and saving, so, for example, in percentage of maintenance, budget, or anything like that?

P: So, as a good estimate on our calculations, a one percent improvement in OEE of reliability is worth about 70,000 pounds sterling per site. So that's the benchmark we've got at a high level and were based on labor and profit margin.

I: And have these improvements and savings been achieved in the past already?

P: No, in this business, no.

I: And can you say why not? And in what time frame do you want to achieve those savings?

P: Had not been implemented in the past because the company has focused on finance and profits and looked at headcount in the past. Now in the points where labor is very difficult to get hold of, there is a realization of we can't reduce cost through headcount. We need to look at getting more out of our equipment must be a cultural change we have just been through. In terms of the time frame, it's all pushed into our/ this year, so with an Irish company, so our financial year runs from October two September. So, the savings will be between now and September in our financial year.

I: And how do you track the efficiency of the reliability engineering department?

P: If you look at some of/

I: KPIs, for example, that means.

P: Yeah, so there are the KPIs I mention, so you got your OEE for a site. Your mean time between failure per piece of equipment as well. Also, look at the manufacturing costs per ton as well. Which is not done in the past and the annual spend per asset as well. Particular on the reactive peace, so could be extracting the data understanding to spend on a piece of equipment, from a reactive point of view. It is materials and labor versus the productive spend on checking out the difference. All the time and because reactive maintenance will be more. If you get in contractors out to help you the costs will be high, so we can track the reactive cost versus the proactive costs that help you understand that your reliability department has an impact. And you can also look at the safety aspect as well. A safe site is a reliable site, so looking at the safety metrics all the time as well.

I: And you do that already, or you're intend to use those KPIs?

P: We started to look at that already in terms of looking at number of near misses, number of accidents, number of process confirmations, and behavioral safety confirmations as well. And tracking, that per site.

I: Are there any other aspects that you can use to measure's the effectiveness? For example, reducing production losses or something like that?

P: Yeah, absolutely, so we will also look at the reduction in number of stoppages, the frequency, and those for the duration of those stoppages as well. We also look at the number of root cause analysis investigations being conducted, so expect the reliability department to support with those. And also, look at metrics around the use of the CMS or SAP, or whatever the site uses to make sure that it is being used. So, work orders have been closed in a timely manner, and notifications are being raised on the critical functional location. All was on material cost being assigned and into their/ so using make sure people using a system correctly in order to allow us the data to improve.

I: Now, if you take all those costs into account. What do you think are the particular advantages of a stand-alone reliability engineering department?

P: The main advantage is, you giving somebody the space, the headspace, and time to work on anything we just discussed. We don't have that, people get tied into the day-to-day problems over in the day-to-day issues, the reactive stuff. The advantage of the reliability department is, it's somebody to take a step back and look at the bigger picture, managed by fact, and help move the site to a better place and change, helped change our culture.

I: So, we are already at the last question. Would you like to add or elaborate on any of those questions before?

P: No.

I: You don't have to, you don't have to! Okay, thank you very much.

8.7.15 Transcription Participant #14

Transcription

Participant No. 14

- Further information on the participant: See table in the appendix
- Date of recording: 14.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 15:35 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: The first question is: In which position do you work?

P: At the moment I work as a manager of the maintenance department for mechanical maintenance.

I: And in which positions did you work before?

P: As a normal project engineer in the same company, same department.

I: And how long have you been concerned with the topic of reliability engineering, and in what context?

P: (...) I'm dealing with this subject now for about 14 years it's part of my department, we are, we take care of the machines, and so we have to do our reliability engineering in a certain part. When I started in the company, my first project was to invent something called Vorbeugende Instandhaltung.

I: Preventive maintenance.

P: Yes, so, this was my first job there, and I inspected all the machines and created a tool in is SAP for this work. So, now it's living or working for forty years, fourteen years.

I: So how is your maintenance organization structured, and how is reliability engineering integrated there?

P: Okay, our maintenance organization is structured into three parts. It's the mechanical part, the electrical part, and everything else. I want to say, like streets, train, gas, electricity. Everything that is not directly related to the production department. And reliability engineering, we do a little bit. We have some like we measure temperature, we measure Stromaufnahme (current consumption) I don't know the technical terms. We have our maintenance workers who check the machines regularly. Maybe once a week, sometimes every two months. It depends on the subject they are looking for. So, we have a structure but not a very big one.

I: So, from your point of view, you just explained how the maintenance Organi/ or how the maintenance is structured on your site. And if you could change it, do you think it's a good way, the ways the maintenance organization is structured, or would you like to do it differently?

P: I personally would like to do it a little bit differently. I would like to do more overhauling of the machines automatically. So, more measurement, or, yeah, everything you can get on the market. But it's, we have very, very old machines. So, it's quite difficult to build these things into the old technique. And I also could imagine having, just maybe, four or five people doing nothing else but reliability engineering. This is not the case.

I: Yeah, so, if I go you right, your site so far doesn't have a reliability engineering. It's integrated into the maintenance department. Is that correct?

P: Yes.

I: Okay, and do you intend to introduce a stand-alone reliability engineering department?

P: No.

I: So, why not? Why is that?

P: We thought about it for some time, fourteen years ago that was a topic, but we reduced our Mitarbeiter.

I: Workforce.

P: Workforce from almost 800 to 440 now. So, this is not an option. Because we don't have the capacity to do so.

I: I understand. So, talking about different companies, so not your company. Why do you think more and more companies are introducing a stand-alone reliability engineering department.

P: When you have a company that is fully booked. So, you have to produce all time you can. It makes sense because you improve the, Was heißt Anlagenverfügbarkeit? (what is the word for equipment availability?) So, you make sure that your machines are working when you need it. So, but at the moment we are in a position where sometimes we don't have work to. So, everything stands still, and then we can use the people who are there to do this work. So, at the moment, it's more important to save money than have machines that work 100 percent.

I: Understand, but you said fourteen years ago it was different. And, what was the reason why you were talking or thinking about introducing a stand-alone reliability engineering department fourteen years ago?

P: Fourteen years ago, we were, I would say, in my department 60 percent more working force and we produced 24/7, and there it made sense. Very, we had, some, little bits like this. We had some, one technician and four people from the workshop who did nothing else but, not really reliability engineering, but

I: Prevent maintenance, as you said before.

P: Preventive maintenance, yeah, that's the word. So, and it worked quite good. But when they all the people left it, I wasn't able to keep this up because otherwise the other groups we work three shifts. There are not enough people on these shifts to look after the machines during production when something breaks down, or, yeah, things like this.

I: And, what types of improvements and savings would you expect from implementing a reliability engineering department?

P: That I can save a lot of time for my working people, of my workforce. Because, yeah, it's easier to have a system where the machine tells you that something is wrong. Instead of sending somebody to look and then see if, maybe, it's already too late. So, it's better to know in forward that something is happening there. And this is, we have on our most important machines we do have this. For example, the mill, we check a lot of parameters. But, not all machines.

I: Yeah, and can you quantify these expected improvements and savings. So, for example, in, well, ten percent more of machine availability or five percent in reduction of maintenance cost or anything like that?

P: Yeah, we already, in our company or our production is parted into two areas. One is called the warm part because there the production or the product is made from the oven and then milled. There we already have, if you just look at the technical side, we have 95 percent of Anlagenverfügbarkeit.

I: Availability of machinery.

P: Yeah, and in the so-called cold part, where the product is shaped and measured and all these things. We are a little bit worse at around 90, 92 percent. So, to get better production reliability, it's difficult, because we are already quite good at this. But we also put a lot of money into it, so maybe, for us, the benefit would be more on the saving money side. Because sometimes, when something breaks down, it doesn't need a lot of time to change it. Maybe two or three hours, but to repair these parts that break down sometimes costs about 50,000 euros. So, I would say this would be a bigger benefit for us.

I: Yeah, I understand.

P: I can say maybe 10, 15 percent, maybe, but not more.

I: So, you said that you are already doing a preventive maintenance approach. So, did you achieve any, well, improvements or saving through that?

P: Yeah, before I started it fourteen years ago, we had maybe 70 percent of. Ich habe das Wort schon wieder vergessen (I forgot the word already). Anlagenverfügbarkeit.

I: Machine availability.

P: Yeah, it was around 70 percent, so the improvement was about twenty percent, that's a lot.

I: I understand. And how do you track that? Do you have any KPIs, or anything like that, which you measure on a regular basis?

P: Yeah, we have daily reports. They are SAP-based. And everything that happens, not only technical things but also when they have to change, for example, the knives at the shears. This is also reported, or if the production has a break. This is also reported. And from this, we can see exactly which part of the production has the biggest problems. Which part has the most problems numerically. And we can also see which are the longest brakes, for example. One machine has twenty breaks, but only each one is ten minutes, and another one is only one, but this takes three days to fix it. So, and then we can choose where to put our emphasis on. Normally, on the one that is only one break but it takes three days. This is more important than the small ones because you can't prevent everything.

I: Okay, and are there any other aspects you can see, or you can use to measure the effectiveness, for example, reduction in production losses or anything like that. Do you measure that as well?

P: Yeah, we measure the amount of produced of products. So, we knew yesterday we had maybe 550 pieces produced, and when you have significantly less, you know that something, maybe, the organization wasn't good or maybe it was because of technical

problems. And sometimes we also lose some products because of technical problems. For example, when you have a hot product, and you have some problems, and it can't be finished, the production can't be finished for this one. You will lose it so, and this is also what we measure. And there we, a few years ago, or many years ago, we had, for example, in a week, maybe, ten products lost. And today it's maybe four or five. So, you can measure this and something that we do.

I: Very good, now, if you take all the costs into account, because reliability engineering or preventive maintenance is a costly thing to do. So, what do you think are the particular advantages of a stand-alone reliability engineering department?

P: I think the biggest advantage, that you have someone who is only focusing on this subject. We have got the problem that, sometimes everything else is more important than this. And so, we say, that the daily trouble eats up our time for this subject, so it would be an advantage that there is someone who can only focus on this.

I: Yeah, I understand. So, the last question: Would you like to add or elaborate on any of those questions? So, you have the last word.

P: What do you mean by it?

I: Yeah, well, if there is anything you want to add which was not in the questions before.

P: No.

I: No, okay, then thank you.

P: I can't really remember what I said.

I: Okay, thank you very much.

8.7.16 Transcription Participant #15

Transcription

Participant No. 15

- Further information on the participant: See table in the appendix
- Date of recording: 16.12.2021
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 16:48 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: First question: In which position do you work?

P: I'm maintenance manager in a metal preparation plant.

I: And in which positions did you work before?

P: The same position, maintenance manager in various heavy industries of iron casting, steel rolling, and limestone.

I: And how long have you been concerned with the topic of reliability engineering, and in what context?

P: Reliability Engineering is, I must say, the time of my working life, which is now, I would say, around 25 years. And it's in different, what shall I say, expressions.

I: Okay, so what does that mean?

P: From reliability engineering or reliability management from the simple task of greasing and lubrication, has been mentioned before, and up to design and construction of the machine for good and simple, yes, work or the lifecycle of the machine.

I: Okay, thank you. And how is your maintenance organization structured, and how is reliability engineering integrated there?

P: The structure is that we have three shift teams in both faculties, mechanic and electric. And we have in both areas day shift teams which cover, more or less, so, the shift team handles the daily business of breakdowns and reliability management. And on the day shift, we cover the more complicated and returning topics which occur every week. Maybe, we have a planning system that every Monday, every Tuesday, every Wednesday, planned standstills for the reliability management of the facilities.

I: And does your site already have a stand-alone reliability engineering department?

P: No, no, it's all integrated into the normal business of the teams, but it's no separate dedicated organization for that.

I: Okay, and you just explained how the maintenance organization looks like at your site and if you could change it, would you say it's a very good organization, or would you like to do it differently?

P: In the former organization, I tried to organize it in a separate team, but we were not finished with it when I left the company. I think it could be helpful to have a dedicated team for that, with a dedicated structure from top to bottom. Now it's, more or less, a part of everything and so the importance of it is not every time so high as it should be.

I: So, that means you would like to have a reliability engineering department if possible?

P: No, not necessarily.

I: Okay.

P: It works. It works like it is, I have a technician who organizes it, organizes the inspection and reliability tasks. But it could be increased a little bit, but only a little bit, I would say.

I: So, now talking about companies in general, so not your company. Why do you think more and more companies are introducing a stand-alone reliability engineering department?

P: I think if it is a stand-alone department, it could help to separate it from the other big topics like breakdown management and improvement management, which are totally different from the continuously working reliability work. So, the breakdown is when it occurs and the plan is different tasks for a longer period of time or for more work to do in a block. And the reliability work is, more or less an ongoing process which is with small changes to get improvements.

I: Understand, so, if you had a reliability engineering department, what improvements and saving would you expect from such a department?

P: (...) In euro or in percentage or in, not I would expect less unplanned stoppages, where we are at the moments on a quite good level. We don't have many unplanned stoppages, so you can say we have good reliability engineering. The organization of it, I would say, could be improved. So, that it is more structured with a better follow up of all the reliability tasks where we are now, maybe, wasting time on tasks which are not necessary? I think that there is room for improvement to look after the work done, to optimize the workload of the people.

I: There could be some other points like reduction in maintenance budget or anything like that. Have you thought about that before? So, maybe, well, you could say I would like to reduce my maintenance budget by three percent through reliability engineering. Or I would like to reduce my production loss by five percent or anything like that.

P: You could say that. I'm not convinced at the moment to blow out his figures.

I: Yeah, no problem, no problem.

P: From the current point of view, I'm not able to give such figures on our actual situation.

I: Understand.

P: I would say we are on a good level by reliability. I would say there are about three or five or maybe ten percent room for improvement, but I'm not sure if it is on more production, I don't see it because we/ the machines are running on the full level. Maybe, its reduction of unplanned breakdowns which result in spare part or external workforce, or internal workforce which is bound with it, but it's difficult to give their detailed figures.

I: Yeah, I understand. But you said you're doing some reliability work. So, even if it's not called reliability engineering department, but have you achieved any improvements through this, well, yeah, reliability work, preventive maintenance, so to say?

P: Yeah, it is absolutely better that we have, in one department, as I know right because it started before I entered the company, three and a half years ago. And, I think they improved the reliability of the line from around 70, 80 percent, roughly to above 90 in the last three or so, in the years minus three to minus five before I entered. And now we improved, in the last three years, by again two to three percent. I would say so. We are now close to 95, 96 percent effectiveness.

I: That's impressive.

P: Technical effectiveness, not OEE.

I: Of course not. And how do you track that? How do you track the efficiency of the work you are doing? Do you have special KPIs, key performance indicators, or anything like that?

P: Not really, we only have this technical efficiency in one line where it is followed up by the production. It's not a key indicator that is measured where we are leveled to. It's only for us—a target which should be achieved.

I: Okay.

P: But, that's/ there is no point that we discuss about the last year we had 95, next year we want to reach 96 by that and that and that. It's just a guideline to be on.

I: Are there maybe any other effects where can see the effectiveness, for example, in the reduction in the number of work orders for the maintenance department or anything like that?

P: It's not tracked, I would say at the moment.

I: Do you use SAP?

P: (...) Können wir das außerhalb des Protokolls diskutieren? (Can we discuss this outside of the record?)

I: Unfortunately, no.

P: Nein (no), no, we don't use SAP.

I: Okay, I see.

P: At that point, at that point, we don't use SAP.

I: Okay, I understand. And now, if you take all these costs into account. Because reliability engineering or preventive maintenance or whatever you call it, it's expensive. So, what do you think are the particular advantages of a stand-alone reliability engineering department?

P: Isn't this the same question?

I: Roughly.

P: I don't know. I don't know what to say again because, for me, the advantage of a/ what I said before.

I: Okay.

P: That I get a more stable process, that I can control the reliability tasks better and by that, maybe, step by step, get better control and overlook over my, over the performance of the production machines. That's, I would say, is an advantage. That I know how the machine is working and I know when I have to do not, not regular occurring works like breakdowns. So, I reach, I will reduce the breakdown rate, and I will, maybe, reduce the planned stoppage number. Just by extending the time of use between interventions. But I did several interventions, so I did/ reliability engineering for me is: I make smaller interventions but, more often, which don't disturb the production. On the other hand, I have breakdowns, I do never stops the machine when not necessary, but when it happens unplanned and with a better, with a bigger, bigger effect and worse effect. So, that's the difference for me between planned reliability and not done reliability. Können wir kurz stoppen? (Can we stop for a moment?)

I: Of course.

P: Ich muss mal kurz and Telefon gehen. (I have to answer the phone.)

I: Okay of course, kein Problem. (No problem) (The interview was briefly interrupted.)

P: Ja, auf den habe ich noch gewartet. (Yes, I was still waiting for that one.)

I: Okay, no problem. So, one question left, would you like to add or elaborate on any of these questions? So, you have the last word.

P: I have the last word. (...) I (...) during the interview, I would say, or by dealing with this topic, I would say it is an interesting topic. And as it is discussed a lot in the past. But it would be nice to have compressed results and clues to deal with this topic to get a kind of guideline. What could I do to reach this and that by implementing a stand-alone reliability department? Which I don't have, but maybe such a guideline could give me help to introduce it or to implement it.

I: Okay, so, thank you very much!

8.7.17 Transcription Participant #16

Transcription

Participant No. 16

- Further information on the participant: See table in the appendix
- Date of recording: 04.01.2022
- Place of recording: Online via Microsoft Teams
- Interview conducted by: Uwe Christian Bußmann
- Recorded by: Uwe Christian Bußmann
- Transcribed by: Uwe Christian Bußmann
- Duration: 20:49 min
- Recording device: Smartphone
- Linguistic peculiarities: The interview was conducted in English. The interviewer is not a native speaker. The participant is not a native speaker.
- Transcription notes: The interview was completely anonymized.

Start:

I: So, first question: In which position do your work?

P: So, I'm the production manager and I've got in my department, in the production department, a production team as well as a maintenance team and also the shipping team.

I: And in which position did you work before.?

P: So, I also was a maintenance manager in Canada for three years. For another, for the same mother company but another division, and also worked in quality and also in process, sorry, in the project engineering, in project management and product development, so, quite a few things.

I: And how long have you been concerned with the topic of reliability engineering and in what context?

P: I'm started, I think when I went to Canada, so, 2011 and starting there, even though I changed jobs afterward, I was still at them. Because in the company I worked for we had a lean program which was called World Class Manufacturing and so we had the audits and so even I was audited as a quality manager. I also got information about the reliability pillar, we called it, so we kept the information. so pretty much since 2011 on the topic.

I: And how is your maintenance organization structured and how is reliability engineering integrated there?

P: So, we have a small team: one maintenance manager, two mechanics, one electric guy. Reliability engineering is more something that we, we, what we called the pillar, so we do have a pillar for reliability which concerned the maintenance. Where we look at some key figures like the MTBF, MTTR and so far. And look at the analysis of breakdowns and there's also a central structure with an, pretty much a chief person who's specialist in this domain and then also person especially for the global lean project for the whole company.

I: And, well, you now explained how the organization looks like at the moment, and if you could change it, would you say it's a very good organization or would you like to do it differently, especially in regards to reliability engineering?

P: Well, I think the maintenance manager I have, he is good technically, but definitely you see that he doesn't really master the tools and he is not, he understands the idea of lean, because, I mean, lean is nothing else but for me but common sense, which means don't waste things. Don't waste your time, don't waste money, don't waste material, but putting into practice is another thing and more and more lean also means using, well, using electrical tools and is a bit, it's not the most comfortable with a computer, so that's where I see where he needs the support from my side, but technically it's good. The organization, generally speaking, I think, would help if we were more into teams with production teams, we talked about to optimize, to separate the production into areas, and to have one dedicated person per area. So, it's not just, you know, it's not to have production versus, against maintenance to have, even though it's a small team, so, to have it practical try to build a matrix at the plant level where you have, of course, maintenance manager especially for maintains, but each person in the maintenance, each of the mechanics and electric, the electrical guy is then dedicated to an area, which also means I need my people to have more training. Because I need not just mechanics were people at least have what called in Germany the (unintelligible, indistinct), in English the first level electrical. So, at least he does some things. So, we don't always depend on one guy for electrical, for example. So, it might seem complex, but we can keep it on a simple level, you know, to, but people have to go with it, cause if you don't pay attention people say: no, I'm not, it's not my boss anymore, because I'm in a team, your boss assigns a vacation better in the teams it means if something happens, you should in the area, you should know about it.

I: Understand, and well, I didn't get it, at the moment now, do you have a stand-alone reliability engineer or technician who is doing 100 percent reliability work or not?

P: That's a person in the central organization. It's not at the plant level, so it's more like a, like an external consultant, pretty much.

I: Understand.

P: Company internal, but he comes every now and then, does an audit and gives us consulting on which document to use on which, and then we also have who train the people on green belts, black belts and, so, for the lean part really.

I: And are there any ideas to have a reliability engineer, or technician, or specialist on the plant level so far?

P: We thought of it. We had a facilitator but we noticed the size of the plant because is just 40 people, it's not worth it, or it doesn't mean/ it's good to start with a person like that, but once you're at a certain level, you shouldn't have that person anymore. Because then everybody should know the principles and you shouldn't need a person specialized for that.

I: I understand, yeah.

P: There is always a discussion about having a special person for that. Then we want him to train people and then once the people are training should ideally evolve and you don't need that person anymore.

I: And so, now talking about your company, but about companies in general. So why do you think are more and more companies are introducing a stand-alone reliability engineering or a stand-alone reliability function?

P: Well, it depends on what level you make it, but, I mean, it means you still notice that you need somebody for me, hands on, it is good to have consultant type of person but you need somebody who can really/ who go with the people in the machine, get his hands dirty. And that's my point of your view at least. And really show practical examples because the people have the ideas, but you do need somebody to help deliver the ideas, you know, kind of like Sokrates helping people delivering the ideas. It's, people know what they have to do, I mean, they know the machine but sometimes the need first assurance that they will get, that will be listening to. Also, assurance that they will get money for the project and time. And then things will get done. So, I think that's why people notice that, and I think a lot of companies notice it's a culture change. So, for a cultural change, you need somebody specific and it's not something that happens in one year, that's why does take, I would say, five to seven years. At least where you do need people with that function but ideally, it's a function that should pretty much dissolve itself. Or, once that job is done actually, they are not needed anymore. Ideally, but which means practically afterward the person can get another job, a job with the part of the job because it's not gain knowledge of the plant. But for me, it's while/ if you look at big structures, have to be careful that you do not make the huge paperwork administration like reliability engineering has to stay practical. It has to stay lean. I mean, you know, lean is lean. So, if you have a department just for lean. Why do have a department for lean? It's kind of contradiction in terms.

I: Understand and

P: You have to be careful not to build, not to build a bible that is not useable. I've seen that happen. Also, in the company where we, we got forms that we had to fill in. I said: wait a minute, where here we are, you know, I've got four people in my department. Why do I need to make a big board with all the numbers and in concerning for the safety? Safety is important, but do I need to follow four people separately on a board or can I follow 40 people on one board. What does it bring me? Because you needed it. Yeah, I need it. But then I spend more time filling an Excel sheet than I do. And then you create administration and not improve reliability.

I: Understand, and are these are the same reasons why you have a reliability central function in your company or are there other reasons for that, maybe?

P: Well, it's better to keep expertise of some people and also because some things are better centralized, because we don't have enough, I mean, we (unintelligible, indistinct) I mean, of course, if we had in full time, we were using full time. But, you know, you see, it also costs money. What does he bring? And for example, in our plant the biggest concern is actually not breakdowns, but it's a material over-usage. Which is actually not on the pillar reliability but more on the pillar of efficiency's industrial efficiency. So, you know, if I don't have a huge issue on breakdowns. Also, yes, I need to be a training, I need to know to do a breakdown analysis, but I don't need to train my people on it because the main issue for the plant is material usage. So, we have to see also as the plant that we don't put energy where, you know, its take care of the biggest issues first. And if your biggest issue is not breakdowns, okay, then, of course, we have breakdowns, but the others cost more, take care of the others before you look at breakdowns. Also, I love to take out breakdowns, and also there is often a discussion. Yeah, and find a solution for it and then you make a full analysis. And a full analysis means it takes time and people. And you know, of because I can make a full analysis on light bulb burnt out to my office. I can just I'm gonna change it and it's not even worth the analysis. If it starts to break down, if we really have to change light bulbs, so, I may have to do one. But there was an interesting thing that happened during an audit where we looked at the high-pressure pumps were breaking down. And the project group found that there are some metal particles coming probably coming from the old pipes, plugging the machines. So, they put filters in. And there was almost a philosophical discussion between the two auditors. One said: Okay, great you're done. You have saved, you made a lot of savings, and the other person said: No, there not done, because I have not found the reason why we have these metallic parts in the piping. And the other person said: Yeah, but to get to look at/ that's true. Theoretically, you are not finished, haven't found the root cause, but we found something which doesn't cost a lot, which is a filter that is to change. And putting energy and time of people to find the reason why even in theory it's needed, then you're gonna create more cost than what you have now for the filters. So, it's a good time to stop.

I: Understand.

P: Also, we need reliability but we also, also for me not to theoretical, because some points are okay. I mean, like as you know, I can buy for every machine a second machine and I have a backup, it's great. But I'm going to ruin my company.

I: Yeah, but that exactly leads to the next question. So, what types of improvements and savings do you expect from implementing a reliability engineering department?

P: Well, definitely, you know, the classical breakdowns and especially on the continuous production lines. And also, safety-wise, because if, you know, if your system is reliable and don't break down, you don't have incidents and you don't have people going in eventually creating an, or creating a situation where a leaking pump, if you're transferring chemicals, then, of course, it's better to know that this pump has been maintained regularly and you know when the next maintenance is due and it doesn't leak in between. Because it is just leaking, people can get it on themselves, and then you have to repair on a pressure pipe or not, and then it's getting really dangerous. This is also reliability, at means safety for the employees, not just for the plant. For me, that's the first thing, you know, helping reliability means improving safety in the plant.

I: And can you

P: And the savings depends on the project, but usually, it's the first right to the biggest savings from the smaller improvements. And small things can bring a lot of effects.

I: True. And can you quantify these expected improvements and savings? For example, I would like to reduce my maintenance budget through reliability by five percent. Anything like that?

P: I think, depending on the company, anywhere between five and 15 percent is doable depending on where the company stands.

I: Five or 15 percent in a reduction in maintenance budget or in

P: Yeah, in the maintenance budget.

I: Alright, alright.

P: Not total cost for the plant, but it depends on how you compute your total costs. Some plants do it, most plants don't because if you drop your total costs and you look and ok since there's no leak, I don't have also to pay the extra time to repair on the leak. In that time, of course, I can make good products. So, it's a lot of things and side by custom everything, so but that most companies do not do the full cause, because there is quite tedious to do. But there's a lot more behind that. Which I would say there, yes, some savings I've seen, for example, where a chain, it was breaking, a transfer chain. So to transfer product from A to B which was breaking down. Too loose and they want

to tighten it and it went too tight and then it broke. So, we do something very simple. We put marking on a piece of metal, with tape, green in the middle red above and underneath. So, green was the right tension. You know the classical visual. You don't need to be trained also means savings in training time because if things are visualized which is from your key point of reliability, then it's easier to train people to meet you, spend less money and time on training people and there are more efficient, more quickly. And that's also savings.

I: And have these improvements and or savings been achieved in the past, at your plant?

P: Especially for the chain. So, yeah, we are achieved on that. Yes, we achieved a reduction in breakdowns. I think we even went as far as reducing the breakdowns by more than a third. Because we hit the biggest reasons right away. And sometimes is very simple things. It's going to the machine looking at what's happening. And I had a breakdown on a machine was because we had very old heating elements which are being put in and the were not good. And we change them all in, yeah, you know, it seems like normal, but, you know, that's first before you start worrying about your machine or the heater, first check your connections. Everything so protected the connections, because we had the classical hot product dripping on a cable and then you wonder why you have/ see this afterward. But if you don't go look at the machine, you don't see that. And then you can get/ for me, that's where reliability, of course, reliability engineering is also the face in the conception phase were how can you design a machine to be reliable. So, that's also, maybe part of the question, I'm looking more at the end-user, so I think where the end-user, the designer should meet the end-user as we talked about. Because you can design the machine is a great way. But if you don't talk to, the person which is gonna be running the machine. You might make it dangerous for him, even if you try to make it safe. Because you might not have the space or you don't know. Yes, it looks great on paper and even on the 3D-drawing, but if you don't think about how I'm going to take this apart or how I'm going to maintain it, how I'm not going go in once it's all put in. I have got the cables and the grid and got everything then. It may seem great and easy to maintain, but maybe for the person, it's impossible to access. The typical example of a, I don't know, a nut, a grease-connection, which is not accessible. And they never get the grease.

I: Yeah, I understand.

P: So that's been where the loop is between the reliability engineering for me and the person on the machine.

I: And how do you track the efficiency of reliability engineering? Have you, for example

P: For the maintenance, as I said, we look at the meantime to a repair, mean time between failures, we look also of the cost of repairs, and also, yeah, the cost per machine. So that's the kind of thing we look at.

I: Other KPIs, maybe special KPIs for that.

P: Yeah, as I said, the one we a used, mean time to repair, mean time between failures, total downtime per line, and then also the costs.

I: Maybe any other aspects to measure the effectiveness, for example, reduction in production loss or something like that?

P: Yeah, we don't do it now, but that's something that you see indirectly. You can/ what we do not do yet, but could be definitely is to look at the availability of the machine. Which is indirectly downtime. But not only that.

I: Yeah, yeah.

P: That was a classical example, the maintenance is addressing one hour to work on the machine and they forget that before you/ the one hour it's just repair time and they often forget they don't/ they don't compute the last good product to next good product. And that's quite a difference. Because before I have my last good one, I shout down. I should on the machine, I do my lock out, tag out and let the person in. He repairs, unlock, we start, and, again, is usually a much bigger amount. And that usually I see in my career. The discrepancy in perception between maintenance and production. Maintenance says: We were very quick, no issue. And production says: For me, it's not very quick. It takes four hours and the mechanics says: No, it took me one hour and production says: We lost four hours of good product, production.

I: Yeah. And so, of course, reliability is a costly thing.

P: Yes.

I: So, if you take all these costs into account. What do you think are the particular advantages of a stand-alone reliability engineering department?

P: For me, once more, if we avoid the risk of being too bureaucratic in some companies is definitely some help if you have also standardized machinery, some nice equipment. Because you can also copy things over from plant to plant, bring that message from plant to plant, and help. I mean, of course, it's good to/ you have to talk to the person using the machine, but it's also clear that you have to think ahead. When you plan a machine, you can not plan everything, but you do have people who think ahead and you don't have the time and you're running production. Think about how is machinery put in and think about the access and maintenance and how with this up impact

machine. So, it does make sense to have a department once you have a certain critical size which depends and every company then.

I: So, the last question: Would you like to add or elaborate on any of these questions?

P: For me, reliability engineering philosophy, once more, there's a design part, of course. But the thought process of preparing things and, once more, again the idea that if you avoid to be too bureaucratic and too big structure because then you have the risk of spending more money on your overhead than you did on the advantages. So, to look at that with also there, we have to be critical about what costs come from a central structure. At what point it makes sense and at what point it's too big. And trust looks ourselves in the mirror honestly and see what did it bring and if you say: I cannot complete the savings well, then you are not good at your job, because you have to be able to see what savings you bought. If not, there's no point in making a project.

I: Okay, thank you very much.