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Lean Technology Management

Development of a Lean Technology Management Model to increase the technological Competitiveness of Companies

DOCTORAL THESIS

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Abstract

This dissertation aims to establish a symbiotic relationship between Lean Management and Technology Management, culminating in the conceptualization of Lean Technology Management. Lean Technology Management represents a strategic integration of lean principles within Technology Management frameworks, aiming to optimize organizational processes and foster innovations. Through the development of a foundational model, this research elucidates the principles and practices defining Lean Technology Management and highlights their potential impacts on organizational performance.

Drawing upon empirical evidence and theoretical frameworks, this study underscores the significance of Lean Technology Management in contemporary organizational contexts. By leveraging technology to streamline processes and eliminate inefficiencies, Lean Technology Management enables organizations to adapt to dynamic market conditions and gain a competitive advantage. Furthermore, this research explores the role of leadership and organizational culture in promoting the adoption and implementation of Lean Technology Management initiatives.

In addition to providing insights into the benefits of adopting Lean Technology Management, this dissertation critically examines its limitations and challenges. Factors such as resource constraints, organizational resistance to change, and context-specific considerations may hinder the successful implementation of Lean Technology Management strategies. Despite these challenges, the study identifies potential approaches to overcome barriers and optimize the effectiveness of Lean Technology Management.

In summary, this thesis offers a comprehensive overview of the theoretical foundations of Lean Technology Management, its practical implications, and future research directions. By integrating Lean Management and Technology Management, Lean Technology Management becomes a holistic approach to organizational optimization in the digital age. Through continuous scholarly inquiry and practical application, Lean

Technology Management holds promise in enhancing organizational resilience, agility, and sustainability in an increasingly complex and competitive landscape.

Zusammenfassung

Diese Dissertation hat zum Ziel, eine symbiotische Beziehung zwischen Lean Management und Technologiemanagement herzustellen, die in der Konzeptualisierung des Lean Technology Managements mündet. Lean Technology Management repräsentiert eine strategische Integration von Lean-Prinzipien innerhalb von Technologiemanagement-Frameworks, die darauf abzielt, organisatorische Prozesse zu optimieren und Innovationen zu fördern. Durch die Entwicklung eines grundlegenden Modells werden in dieser Forschung die Prinzipien und Praktiken dargelegt, die Lean Technology Management definieren, und deren potenzielle Auswirkungen auf die organisatorische Leistung verdeutlicht.

Gestützt auf empirische Belege und theoretische Rahmenbedingungen unterstreicht diese Arbeit die Bedeutung von Lean Technology Management in zeitgenössischen organisatorischen Kontexten. Durch die Nutzung von Technologie zur Optimierung von Abläufen und zur Beseitigung von Ineffizienzen ermöglicht Lean Technology Management Organisationen, sich an dynamische Marktbedingungen anzupassen und einen Wettbewerbsvorteil zu erhalten. Darüber hinaus untersucht diese Forschung die Rolle von Führung und organisatorischer Kultur bei der Förderung der Übernahme und Umsetzung von Lean Technology Management Initiativen.

Neben der Bereitstellung von Erkenntnissen zu den Vorteilen der Einführung von Lean Technology Management untersucht diese Dissertation kritisch deren Grenzen und Herausforderungen. Faktoren wie Ressourcenknappheit, organisatorische Widerstände gegen Veränderungen und kontextbezogene Faktoren können die erfolgreiche Umsetzung von Lean Technology Management Strategien behindern. Trotz dieser Herausforderungen identifiziert die Studie potenzielle Ansätze zur Überwindung von Barrieren und zur Optimierung der Effektivität von Lean Technology Management.

Zusammenfassend bietet diese Arbeit einen umfassenden Überblick über die theoretischen Grundlagen von Lean Technology Management, die praktischen Implikationen und zukünftige Forschungsrichtungen. Durch die Verbindung von Lean

Management und Technologiemanagement wird Lean Technology Management zu einem ganzheitlichen Ansatz zur organisatorischen Optimierung im digitalen Zeitalter. Durch kontinuierliche wissenschaftliche Untersuchungen und praktische Anwendung verspricht Lean Technology Management, die organisatorische Widerstandsfähigkeit, Agilität und Nachhaltigkeit in einer zunehmend komplexen und wettbewerbsintensiven Landschaft zu verbessern.

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Abbreviations

LM	Lean Management
TM	Technology Management
LTM	Lean Technology Management
LTMM	Lean Technology Management Model
R&D	Research and Development
SLR	Systematic Literature Review
FMEA	Failure Mode and Effects Analysis
VC	Visual Control system via KPIs
JIT	Just in Time
CIP	Continuous Improvement Process
TOC	Theory of Constraints
QFD	Quality Function Deployment
TQM	Total Quality Management
TPM	Total Productive Maintenance
VSM	Value Stream Mapping
5S	Seiri, Seiton, Seiso, Seiketsu, Shitsuke
OEE	Overall Equipment Effectiveness
SMED	Single Minute Exchange of Die
TPS	Toyota Production System
WIP	Work in Progress

PDCA	Plan Do Check Act
ROI	Retorn On Investment
P	Problem
RQ	Research Question
PCBA	Printed Circuit Board Assembly
MVP	Minimum Viable Product
DNA	Deoxyribonucleic Acid
APQP	Advanced Product Quality Planning

Part I

Research Intent

1 Introduction

This study delves into the intricate domains of Lean Management and Technology Management, synthesizing them into a cohesive framework termed Lean Technology Management. The overarching aim is to pioneer a model that not only optimizes but also revolutionizes the efficacy of current Technology Management methodologies. To achieve this goal, a comprehensive exploration of pertinent literature delineates the landscape within which this study operates. Through meticulous analysis, meticulous documentation, and the systematic formulation of a theoretical framework, the foundational groundwork is laid. This theoretical edifice serves as the scaffolding upon which empirical investigations are conducted, affording validation and refinement iteratively. As empirical findings coalesce with theoretical underpinnings, they synergistically inform the development of the definitive Lean Technology Management Model. Through this iterative process of theoretical refinement and empirical validation, the study endeavors to carve a path towards heightened efficiency, effectiveness, and adaptability in technological endeavors.

Furthermore, in Chapter 1.1 Research Gaps and Relevance, aspects and arguments highlighting the absence of representation of the subject in existing literature are summarized. Subsequently, in Chapter 1.2 Research Objectives and Research Questions, the problems to be addressed, along with their resulting research questions, are presented. Finally, Chapter 1.3 Research Design and Structure of the Thesis, provides an overview of the research design and introduces the structure of this thesis.

1.1 Research Gaps and Relevance

According to the literature review from Sinha and Matharu (2019), an exponential increase of papers dealing with Lean Management were published in the last three decades. Their observation shows that Lean Management has been adopted by both developed and emerging economies. As a result of the work done, a classification on the basis of themes is performed. This gives an overview of linked themes research has focused on. This list (lean adaption, lean performance, leanness, lean supply chain, lean and other value creation tools, lean epistemology, organizational theory and lean, lean and sustainability, industry 4.0 and lean) shows no direct correlation to Technology Management. (Sinha & Matharu, 2019)

In the realm of Lean Management, there exists a vast array of hundreds of methods along with numerous adaptations and expansions. The challenge lies in identifying a clear focus and establishing a standardized approach, which poses a problem for many organizations. Standardization plays a crucial role across various methods, particularly in Value Stream Mapping. It is fundamental that both data collection and methods are standardized to facilitate meaningful comparisons. Unfortunately, this isn't always the case, resulting in significant untapped potential across various domains. (Oberhausen & Plapper, 2017) Furthermore, concerning Lean Management methods, underlying principles are also defined, which vary in their definitions. Here, too, the implementation of standardization could establish a universal approach for applying Lean Management to various management disciplines, thereby enhancing both understanding and results.

Other than that, view similar frameworks for Technology Management are emerged, which were created out of a missing link in Technology Management. This missing link was a comprehensive framework for implementing Technology Management in a company. The need of companies to perform Technology Management on process-based frameworks is covered for now, but there is room for further improvements. Especially, how each processes are conducted in companies. (M.J. Gregory, 1995) Here it is obvious that the combination or application of lean principles in process steps of Technology Management frameworks probably lead to higher efficiency and effectiveness.

The temporal aspect of market entry is paramount in fostering a sustainable competitive edge and fortifying market positioning. The concept of the first-mover advantage is particularly salient in endeavors aimed at expeditiously establishing market presence, thereby eliciting brand visibility. This assertion finds validation in a study cited within the Harvard Business Review. "*Once time was money. Now it is more valuable than money. A McKinsey study reports that, on average, companies lose 33% of after-tax profit when they ship products six months late, as compared with losses of 3.5% when they overspend 50% on product development.*" (Charles H. House and Raymond L. Price, 1991)

Thus, the importance of optimizing Technology Management within an organization to be more efficient, effective, and flexible is underscored. The potential to be harnessed from streamlined and agile Technology Management is significant. While many companies may recognize this potential, there lacks a model or approach to leverage these resources into tangible advantages. Furthermore, the importance of consistently generating innovations is further validated.

Between 30% and 80% of revenue is generated from products that are not older than five years. This rate depends on the business area. (Anne Harris, 2005) For this reason, it is crucial for companies to continually evolve and remain innovative, which entails constantly incorporating new technologies into their operations. Therefore, there is a need to develop Lean Technology Management, and the challenge lies in solving the problem by defining and formulating a model for illustration as well as the underlying concept. Consequently, the resulting research questions arise in Chapter 1.2 Research Objectives and Research Questions.

1.2 Research Objectives and Research Questions

The main objective of this study is to investigate and define the extent to which Lean Management can be applied to the topic of Technology Management. Furthermore, this work is intended to provide a model as a basis for possible applications of lean thinking in the different areas of Technology Management. To achieve the chosen objectives, I defined the following research questions:

P1 *– Lean Management (LM) and Technology Management (TM) have so far only partly been considered together - few connections observable. There are still separate development strands, which are considered separately. Comparative assessment has not been done yet.*

RQ1 – Is the concept of LM useful for TM?

> **RQ1.1** – What does "lean" mean? Are there general accepted definitions? Which meaning of lean is transferable/applicable for TM?
>
> **RQ1.2** – What are the potentials/risks of applying LM on TM?
>
> **RQ1.3** – Which methods and tools of LM are useful for TM?

P2 *– TM is resource intensive and technology evolution is hard to predict. It would be a great competitive advantage for companies, if TM could be used in a more efficient way. A Lean Technology Management Model (LTMM) could help to execute TM more efficiently.*

RQ2 – How can the LTMM support the company?

> **RQ2.1** – How could an LTMM look like?
>
> **RQ2.2** – What are the benefits of applying the LTMM?
>
> **RQ2.3** – How can it help to increase flexibility/efficiency in companies?

1.3 Research Design and Structure of the Thesis

As a first step, on a descriptive level, the main scientific fields, namely Lean Management and Technology Management are described. This includes a systematic literature review. Based on that a concept of Lean Technology Management is created. As a second step, on an empirical level, the assumed hypotheses are examined by means of expert interviews (n=29). Finally, the model is reviewed and revised by reflecting and interpreting the gained knowledge. The overview of the described process is given in Figure 1, which can be seen below.

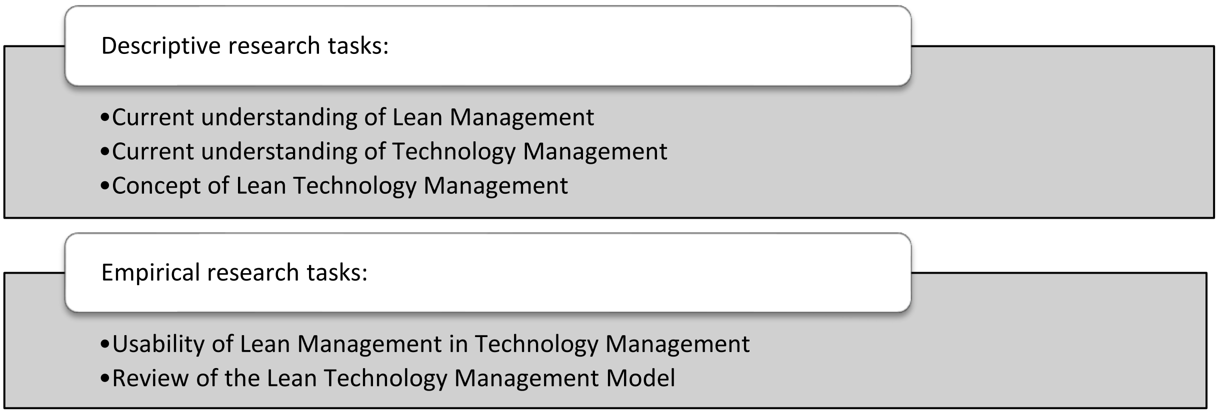

Figure 1: Tasks of the research

This thesis is divided into four parts, which are broken down as shown in Figure 2.

Part 1 outlines the research objectives, questions, and the research methodology for this thesis. In addition, the research gaps, relevance as well as structure is described.

Part 2 offers a comprehensive review of essential background information, relevant theories, and the definitions of key terms. Additionally, it delves into the descriptions and definitions of Lean Management, Technology Management, and their amalgamation, Lean Technology Management. This chapter plays a pivotal role in clarifying the scope of the thesis and serves as the foundation for empirical data collection, including the development of the LTMM and its guiding principles.

Part 3 describes all empirically collected data. This section provides a detailed explanation of the precise methodology for obtaining access to the data and outlines a structured procedure for their subsequent analysis. Finally, the discovered information is presented in a clear and organized manner.

Part 4 delves into comparing Part 2 with Part 3 and drawing conclusions from these comparisons. It juxtaposes existing knowledge with empirically derived insights. Additionally, it introduces and describes the advanced LTMM, while deriving actionable recommendations for companies.

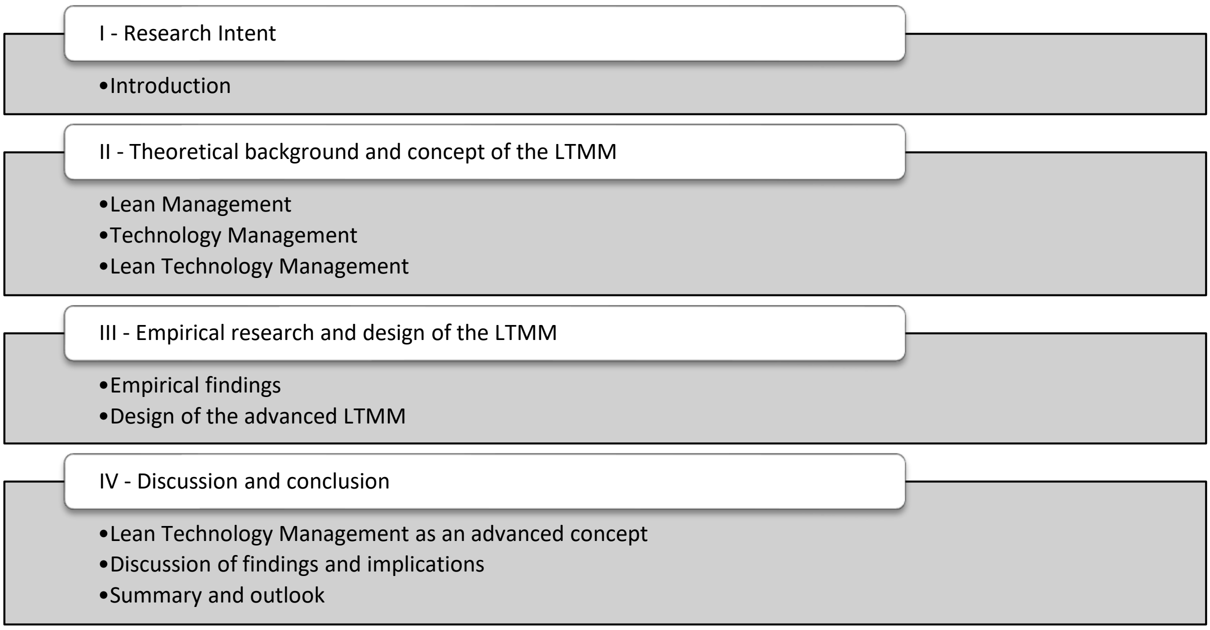

Figure 2: Structure of the thesis

Part II

Theoretical Background

2 Theoretical Background and Concept of the LTMM

2.1 Aims and Structure of the Chapter

This section presents all topics identified based on the literature. It provides a comprehensive overview of both subject areas and their combination. The result of this literature review is a theoretical model that serves as the foundation for the subsequent empirical investigation. In the following Chapter 2.1.1 Systematic Literature Review, the process and criteria for the systematic literature review are described. This is followed by Chapters 2.2 Lean Management, 2.3 Technology Management, and 2.4 Lean Technology Management. These three sections constitute the outcome of the systematic literature review. Furthermore, in Chapter 2.4 Lean Technology Management, a theoretical concept of LTMM is developed and explained based on this review and summary.

2.1.1 Systematic literature review

The process involves defining a clear research question, developing a detailed search strategy, applying selection criteria, conducting a comprehensive literature search, selecting relevant studies, and summarizing the results. The literature review is performed as a systematic literature review as described in (Saunders et al., 2019). The Figure 3 shows the procedure. The search itself is based on research questions and resulting keywords. Search was performed at following databases: SCOPUS, Web of Science, Google Scholar, and Springer Link.

Next is Chapter 2.1.1.1 Exclusion Criteria, where areas and content not considered in the review are listed. Furthermore, Chapter 2.1.1.2 Search Keywords, presents all relevant keywords, and finally, Chapter 2.1.1.3 Search Procedure, explains how the search was conducted.

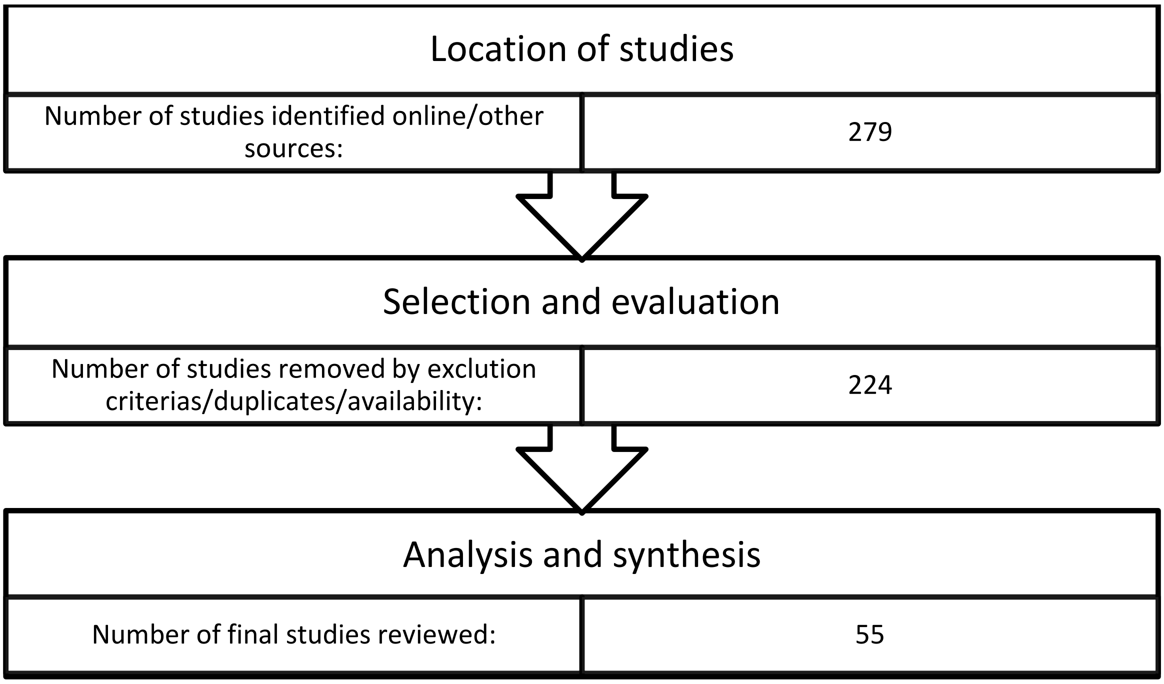

Figure 3: Flow diagram systematic literature review (Saunders et al., 2019)

2.1.1.1 Exclusion criteria

The following list shows exclusion criteria for selecting the relevant publications.

- Publication is not written in English or German.
- Full text is not available.
- Following industries related content: Healthcare, military, navy, biometric engineering, construction engineering, education, agriculture, and motorsport.
- Publication is not found by initial query through the specified keywords.

2.1.1.2 Search Keywords

The starting points for the literature search are the two main topics. Lean Management and Technology Management as a term in itself and possible combinations thereof. Relevant for the search are also possible logical combinations e.g., AND/OR combinations and alternative spelling of the different keywords, which are not listed in Table 1.

Keyword
Lean management and technology
Lean innovation and technology
Lean development and technology
Lean transfer and technology
Lean strategy and technology
Technology management and lean
Technology development and lean
Technological transfer and lean
Technological strategy and lean
Lean technology management
Lean technology development
Lean technology innovation
Lean technology transfer
Lean technology
Lean R&D
Leanology

Table 1: List of relevant keywords

2.1.1.3 Search Procedure

The literature search utilized the databases SCOPUS, Web of Science, Google Scholar, and Springer Link. While not all online databases offer identical search functionalities, their structures are notably similar. SCOPUS proved to be particularly effective for targeted searches. The following steps were employed during the search:

- Access the online database and, if required, navigate to the designated search section.
- Modify pertinent settings related to search languages, open access parameters, and other relevant criteria.

- Employ quotation marks to encapsulate the search term, thereby ensuring meticulous consideration of word order within the database.
- Replicate the aforementioned process for all designated search terms. Proceed to the subsequent database and recommence the procedure accordingly.

The following Figure 4 provides a broad overview of the available literature identified during the execution of the aforementioned process.

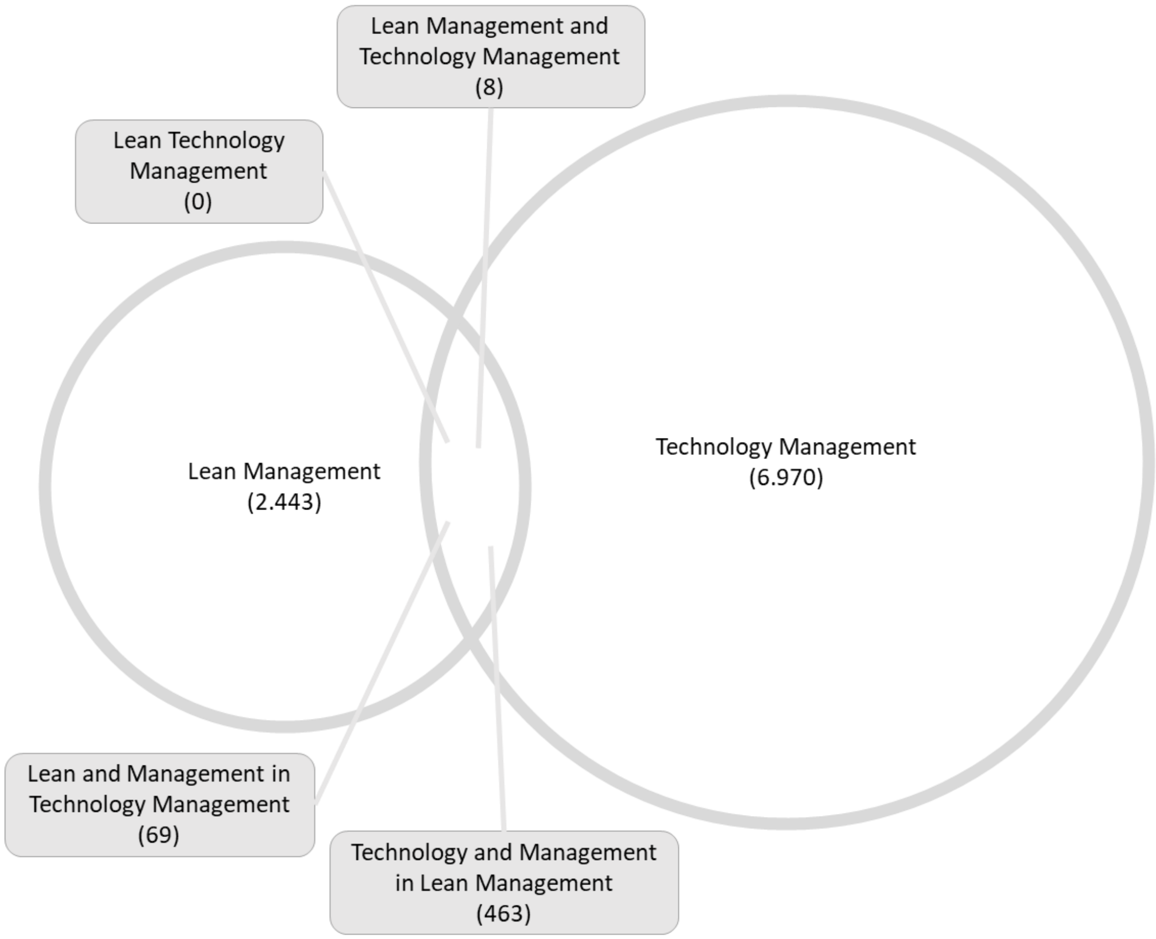

Figure 4: Core domains and number of publications found.

Furthermore, it has been shown that both books and journal articles are relevant to the topics covered. Below in Table 2 is an overview of the journals from which content for this work has been sourced.

Journal
American Journal of Applied Sciences
Business Process Management Journal
Business Strategy and the Environment
European Management Journal
International Journal for Quality Research
International Journal of Advanced Manufacturing Technology
International Journal of Automotive Technology Management
International Journal of Engineering and Technology Management
International Journal of Engineering Business Management
International Journal of Innovation and Technology Management
International Journal of Lean Six Sigma
International Journal of Manufacturing Technology Management
International Journal of Mechanical and Production Engineering Research and Development
International Journal of Operations & Production Management
International Journal of Production Economics
International Journal of Production Research
International Journal of Productivity and Performance Management
International Journal of Productivity and Quality Management
International Journal of Project Management
International Journal of Quality & Reliability Management
International Journal of Six Sigma and Competitive Advantage
International Journal of Technology Management
Journal of Advances in Management Research
Journal of Business Research
Journal of Business Venturing
Journal of Cleaner Production
Journal of Engineering and Technology Management
Journal of Engineering Manufacture
Journal of Industrial Engineering and Management
Journal of Intelligent Manufacturing
Journal of Logistics, Informatics and Service Science
Journal of Manufacturing Systems
Journal of Manufacturing Technology Management
Journal of Operations & Production Management
Journal of Operations Management
Journal of Product Innovation Management
Research-Technology Management
Strategic Management Journal
Sustainability
Technological Forecasting and Social Change
Technology in Society
Technovation
The TQM Journal/Magazine
ZWF Zeitschrift Für Wirtschaftlichen Fabrikbetrieb

Table 2: List of relevant journals

2.2 Lean Management

The term Lean Management was described and defined in 1991 by James P. Womack, Daniel T. Jones and Daniel Roos. Their detailed research showed the origin of Lean Management comes from the 1950's. Japanese engineers inspired by Ford's plant in Detroit developed the well-known Toyota Production System. This concept is the basic idea of Lean Management. (James P. Womack, Daniel T. Jones, Daniel Roos, 1990) However, a detailed overview of the origins of lean is given by the systematic literature review of (Stone, 2012). All known and related terms associated with lean are well and clearly presented. The original origin of lean comes from the field of production, known as the avoidance of the 7 types of waste: overproduction, inventory, motion, defects, over-processing, waiting and transport. (Souza & Alves, 2018)

Lean Management is not only about manufacturing. In general, the manufacturing part of a product is just a small part in the whole product creation process. E.g., in the car or truck industry it represents only 15 percent of the human effort to build it. All the other energy is going into engineering, design creation, testing etc. That means Lean Management has the task to bring all those steps and processes into harmony, this is called the lean enterprise. (James P. Womack, Daniel T. Jones, Daniel Roos, 1990) The philosophy strives to achieve a high efficiency, flexibility and effectiveness by removing of non-value-added activities in a sustainable way. This is supported by a high number of available tools to apply Lean Management techniques. It is crucial that each tool is not applicable for each case. Various lean implementation attempts have failed. Misuse and misunderstanding the context of the selected lean tool are the most significant reasons. That is why the complete understanding of the tool, an organization wants to use, is necessary and a suitable fit is given. Further the involvement of all levels of the hierarchy and anchoring the lean thinking mindset in a company's culture, applied with the tool, takes significant effort. This effort is mandatory to be successful on a long-term. (Naeemah & Wong, 2023)

In Chapter 2.2.1 Definition and Understanding, diverse definitions of Lean Management, along with their underlying principles, are expounded upon. Moving forward, Chapter 2.2.2 Lean Methods, provides a comprehensive elucidation of the most prevalent lean methods, totaling 21 in number. Conclusively, Chapter 2.2.3 Summary of Lean Management, succinctly encapsulates the overarching theme.

2.2.1 Definition and understanding

In this thesis, the terms related to lean are described as follows: Lean thinking correlates to the operational culture and philosophy of an organization. Lean principles are the tools to apply such a philosophy and leanness describes the degree of implementation in an organization. As a result, Lean Management is used as a collective term of the described items. (Stone, 2012) The Table 3 below is showing an overview of the different meanings, understanding of Lean Management. Furthermore, the lean principles are detailed in the subsequent chapters: 2.2.1.1 Value, 2.2.1.2 Value stream, 2.2.1.3 Flow, 2.2.1.4 Pull, 2.2.1.5 Perfection, and 2.2.1.6 Standardization. Following this, an examination of the term lean is conducted, including its definition and significance, in chapters 2.2.1.7 What does lean mean? and 2.2.1.8 Why is lean important?.

Table 3: Overview of selected articles providing definitions for Lean Management. Articles are sorted by date of publication.

Author	Type	Year of publication	Definition of Lean Management
Womack & Jones	Books	2003	Toyota Production System as a basic definition of Lean Management and a wide range of possible applications to become a so-called lean enterprise. Focus is on continues improvement by trying to create more value for the customer while using less resources. Lean Management is a way of thinking to concentrate on value creation. (Womack & Jones, 2003)

Hopp & Spearman	Article	2004	Toyota Production System, JIT, SMED, TQM, Six Sigma and lean are a summary of tools for production management. All of them are dealing with the simplification of processes by maximizing the output. Lean Management is more than reduction of waste (Muda), it is a framework striving for enhancing efficiency and customer focus. (Hopp & Spearman, 2004)
Marchwinski & Shook	Book	2004	A business system to organize and manage product development, customer relations, operation activities striving for reduction of needed resources. In the focus are customer and value creation. This results in reduction of waste in different areas by establishing the lean thinking mindset in the culture of a company. (Marchwinski & Shook, 2004)
Königsäcker	Book	2009	The two pillars of Lean Management, former called Toyota Production System, are the concept and practice of continues improvement and the power of respect for people. To ensure effectiveness it is significant to build a culture that truly lives this philosophy. In short, continuous improvement through all employees. (Koenigsaecker, 2009)
Boyle	Article	2011	Lean Management as the dominant approach in manufacturing management, the method has become very widespread, one can almost speak of a

			standard, at least parts of it are used by many companies in different areas. As a result, that Lean Management is that enormous in possible applications has led to many dissatisfying results. In order to be able to implement a positive result or a positive continuous attitude towards the topic, the corporate culture has to change significantly. This change demands every area in a company and must be considered holistically. (Boyle et al., 2011)
Stone	Article	2012	Basically, the lean thinking paradigm distinguishes between waste and value within an organization. Waste is defined as those human activities that absorb resources while creating no value. Lean thinking in practice means continuous identification and elimination of waste in an organization's processes that only value-creating activities remain in the value stream. Lean Management includes the terms JIT, continuous improvement, Six Sigma, theory of constrains, TQM etc. (Stone, 2012)
Singh	Article	2015	Adaption of the system from Henry Ford by the Japanese to a methodology, which is a systematic approach driven by continuous improvement to identify and eliminate waste to pursuit perfection. This management system, the origins of Lean Management, is called Toyota Production System. Lean Management is the countermeasure to avoid "muda". This results in less human effort, less time

			to develop products, and less inventory in order to set a high responsiveness to customer's needs. (Singh & Singh, 2015)
Baker	Book	2015	The philosophy is supporting the needed adaption to the constantly transforming environment, Lean Management is designed to create a culture of change. Consistent maintenance of processes and tasks, which are creating value and delivering that value to the customer. The key elements are a clarity of purpose (customer focus), standard work (documentation, routines), transparency (information sharing), accountability (passion and workforce) and innovation (continues improvement). (Baker, 2015)
Earley & Earley	Book	2016	Using less of everything by maximizing the output. Lean Management (originally called Toyota Production System) is a way of thinking to deal with change, elimination of waste and promotion of continues improvement. The focus on customer's needs and involvement of all employees at all levels is essential for a successful realization. (Earley & Earley, 2016)
Bertagnolli	Book	2018	Lean Management combines methods to optimize or improve processes. Lean principles summarize suitable methods for this purpose. However, lean is more than just a collection of methods and

			principles. Lean has mainly to do with the strategy and culture of a company. (Bertagnolli, 2018)
Bednarek	Article	2020	A well-established philosophy to improve a company's processes, a set of tools and paradigms widely adopted under the name of Lean Management. Core element is to identify and eliminate all types of waste occurring in processes, by differentiating between tasks, which are adding value and one's which do not. (Bednarek et al., 2020)
Bhat	Article	2020	Ensuring value creation, robustness and sustainment of a system by eliminating waste and reduction of variations. Lean thinking enhances process speed and guarantees to contribute value. This results in reduction in cycle time, WIP, costs, lead time, space etc. (Bhat et al., 2020)
Naeemah & Wong	Article	2021	A philosophy which aims to identify and eliminate waste throughout the total value stream of a product. Considering also the whole supply chain network, not only the company itself. The basis of today's Lean Management comes from the originally defined management system from Japan, the so-called Toyota Production System. (Naeemah & Wong, 2023)

From the various definitions, as shown in Table 3, the following summary of Lean Management emerges. It is readily apparent that the Toyota Production System is the origin of the management approach. Furthermore, it can be said that there are clearly defined cornerstones of this approach. These all point in the direction of optimizing processes, products, operations, and other areas and activities in the corporate environment. Hopp & Spearman believe that Lean Management is an integral part of various other optimization systems. In this thesis, Lean Management is described as a general term for all activities that have the goal of generating an increase in effectiveness and efficiency.

2.2.1.1 Value

The value can be defined as the core thing a customer is paying for. It is often hard to define value, but why? From the supplier point of view, it is easier to produce what they are already producing and from customer point of view it is more comfortable to use that what customers already using. This dilemma makes it very hard to get rid of unused features in any areas. That is why it is essential when defining value to concentrate on the main question, namely to analyze and challenge old definitions to see what is really needed. In addition to that it is mandatory to evaluate the value on a higher level. That means value creation often flows through many companies and each one is defining value in a different way. A caused redefinition is necessary to stay on track in case of doing what is really needed in the eyes of the customer. (Womack & Jones, 2003) (Abdallah et al., 2021)

2.2.1.2 Value stream

The value stream describes multiple actions, which are creating a value for a customer and this value is then also realized by the customer. A value stream reveals potential improvements in different depths of a supply chain. This method can be applied in various forms and allows companies to strengthen their overall efficiency. Out of such an analysis will be found different types of value creating. Some will be unambiguously creating value, like painting the frame of a bicycle or flying a passenger to a desired destination. Others will not create value, but they are not unavoidable because technological standards. E.g., inspecting the thickness of coating to ensure a required quality level or an extra step by flying large planes through hubs to reach to ensure a minimum of utilization. These types of waste are type one Muda. Moreover, actions can be found, which create no value. These steps can be avoided immediately and called type two Muda. To eliminate a type one Muda, the application of lean techniques is necessary. Summing up, lean companies have to compete against perfection and not against their competitors. Identify all types of Muda and strive to eliminate them. To master this task a company's skill is to understand and apply the key techniques of eliminating Muda, this is described in the next paragraph. (Womack & Jones, 2003)

Muda is defined as any activity consuming resources without creating any value for the customer. Moreover, a differentiation of type one and type two Muda is given. Type one Muda cannot be easily removed, but in the case of type two Muda, this can be done quickly by using Kaizen. Mura is defined as unevenness in operation. In short, all activities have to be balanced in way that no station, step or employee needs to hurry and then wait. Muri is defined as overburdening the equipment and, or the employees. On a long-term costs in case of bad quality, destroyed equipment and demotivation will occur. (Marchwinski & Shook, 2004)

2.2.1.3 Flow

Flow means to focus on the value of a service or a product. As a first step, the value must be defined and the value stream has to be clear, every party involved has to have the same understanding of value in the specific business case. The second step requires a different thinking and mindset to overcome traditional boundaries of tasks, processes and structures to form a lean environment by removing impediments to the continuous flow of the business case. The third step pretends the business case of backflows. To avoid such backflows, like scrap or any kind of stoppages the involved parties have to rethink specific work practices and tools. As a result, all three steps must be anchored in the improvement process to ensure a long-term benefit. This could also mean in some business cases, that standard processes have to be completely redesigned and a new basis is required to create a lean environment. Flow thinking can be applied to any activity, it is not just related to product manufacturing and the principles are the same as written before. (Womack & Jones, 2003) (Cox & Chicksand, 2005)

2.2.1.4 Pull

In short, pull means that it is only allowed to produce upstream when the customer downstream asks for it. (Womack & Jones, 2003) As a consequence, the pull principle results in less WIP. (Hopp & Spearman, 2004) This means that this principle can be applied in a way where value, value stream and value flow are already defined. Only then does it make sense and one can expect a corresponding improvement. Furthermore it is always the challenge to find the right mix of lean tools, principles, policies that fits to the related environment. (Hopp & Spearman, 2004)

2.2.1.5 Perfection

Perfection strives for the highest possible level of quality and the elimination of all defects or errors in a process or product. In this context, perfection is an ideal state in which everything is done right the first time. The fundamental basis for this is transparency in all situations, which means, for example, that the entire supply chain (every stakeholder) can see everything from everyone. Only then it is possible to identify potential and to trigger improvement actions. Perfection stands for an approach that combines lean principles with the pursuit of perfection.

In practice, this means the continuous application of lean principles to identify and eliminate waste and inefficiencies in processes, while striving for the highest possible quality and the complete elimination of defects or errors. This is an ambitious goal that aligns with the lean philosophy of continuous improvement and customer value, while emphasizing the importance of delivering the highest quality products and services. Perfection is a holistic approach to achieving operational excellence by combining lean principles with the relentless pursuit of perfection in processes and products. (Womack & Jones, 2003) (Moyano-Fuentes et al., 2021)

2.2.1.6 Standardization

In the lean understanding, standards are the basis for stable processes and consistent quality. As a result, the intended and at the same time persistent end state is perfection. This constant striving to zero failure mentality by meeting the customer needs and steady improvement of all related processes are the fundamental requirements and mindset for all involved parties. (Staats et al., 2011) Furthermore, they are considered the only, safest and most efficient way to perform an activity. Standards are often mistakenly seen as a norm, inevitably they have to be seen as a dynamic declaration, which can be adopted to needed changes at any time. The objective is to stabilize processes by reducing the dependency of people to achieve good results although. As a result, all the knowledge is documented and new employees will have an easier training period. An example of an lean method for standardization is 5S. (Bertagnolli, 2018) Standardization improves consistency, reduce variability, and eliminate waste in processes by creating a clear and documented process for completing a task or activity, with defined procedures and work instructions that are followed consistently by all employees. Standardization is important in Lean Management for several reasons:

- Consistency: Standardized processes ensure that tasks are completed consistently and reliably, regardless of who is performing the task or when it is being performed. This reduces variability and helps to improve quality and efficiency.
- Waste reduction: Standardization helps to identify and eliminate waste in processes, by providing a clear and consistent process that can be analyzed and optimized for efficiency.
- Training and development: Standardization provides a clear process for training new employees and helps to ensure that all employees are working from the same baseline of knowledge and skills.
- Continuous improvement: Standardization provides a foundation for continuous improvement, by establishing a clear baseline for performance and providing a framework for identifying and addressing opportunities for improvement. (Monden, 2012) (Hirano, 2009) (Goldsby & Martichenko, 2005)

Some of the key steps in implementing standardization in Lean Management include:

- Identifying the process to be standardized: This involves selecting a specific process or activity that is critical to the organization's success and is possible to standardize.
- Documenting the process: This involves creating a clear and detailed process map, along with work instructions and procedures that outline the specific steps to be followed.
- Communicating the standard: This involves communicating the standard process and work instructions to all employees by ensuring that they are trained and familiar with the process.
- Monitoring and updating the standard: This involves regularly monitoring the standardized process for effectiveness and identifying opportunities for improvement, and updating the process as needed to incorporate best practices and improve efficiency.

Overall, standardization is a key aspect of Lean Management, and can help organizations to improve efficiency, reduce waste, and achieve greater consistency and quality in their processes. (Fullerton et al., 2014)

2.2.1.7 What does "lean" mean?

The definition of "lean" is broadly diversified. There are countless definitions, as this topic has become very important in a wide variety of areas. Consequently, some impressions are given here, which should make the understanding and the attitude behind it clear. In general, "to be lean" means to avoid waste, to be efficient and effective in all tasks, things somebody or something is doing.

Lean has become more and more a standard mindset in companies. It's complexity and totality has grown and are already a large package of knowledge, which needs a lot of attention for complete understanding. Moreover, lean is not just a collection of tools, on the one hand it can be considered from a philosophical perspective, e.g., as a guiding principle. On the other hand, it can be considered from the operational perspective. This refers to the following areas, such as management practices, tools or techniques, which can be observed directly. These should make it possible to setup time reduction, Kaizen (i.e. continuous improvement), Six-Sigma quality, value stream mapping, total preventive maintenance, visual displays (e.g. 5S), Kanban, just-in-time supply systems, process optimization (e.g. Poka Yoke) or preventative maintenance. (Boyle et al., 2011) If lean is about reduction of waste, the term resource efficiency should be mentioned as well. This refers to the economical and targeted use of resources in the area of material, time and space. The efficient use of resources should be the goal of every company. Lean combines methods to optimize or improve processes. Lean principles summarize suitable methods for this purpose. However, lean is more than just a collection of methods and principles. Lean has mainly to do with the strategy and culture of a company. That is why a strategy is crucial for success and the whole organization has to be part of improvement actions. On a long-term, companies which are familiar with lean methods, have a competitive advantage. Lean is the groundwork for making operations, procedures and processes ideal and waste-free. (Bertagnolli, 2018) From manufacturing point of view, lean as its fundamental existence is about reducing the cost of buffering variability. (Hopp & Spearman, 2004)

Lean does not always mean to reduce or eliminate something. At the end of the day, no action in a company is done for its own sake - it is done to offer customers an ideal buying experience and thus encourage them to demand the company's own products and services. If the company earns money and its customers show sustained satisfaction in surveys, this goal has been achieved. Out of that, lean means that a company has to focus on customer’s needs. In addition all the principles and methods of lean, support company's processes to extend the delta between income and expenses. (Künzel, 2016)

> *“People who do the work have to improve the work.”* (Zarbo, 2012, p. 322)

In order to ensure employee-driven change in the company by putting the customer at the center, it is essential to focus on the resources and structures provided. It is the investment in the employee that brings success. Through this focus, the understanding of lean takes on a different meaning, namely away from pure process optimization to internalization in the corporate culture. Thus, after appropriate application, one arrives at a point where employees decide and work intuitively, efficiently and in a way that conserves resources. (Zarbo, 2012)

All beginnings are notoriously difficult, however, after a period of familiarization, the lean idea is a very powerful tool for application in all areas of a company. The starting point is always the value defined by the customer; this is the focus of all considerations. The application of lean principles ensures the long-term success of a company. Furthermore, the key to success lies not only in the application, but the anchoring of the lean idea in the mindset of those involved is decisive. (Womack & Jones, 2003)

2.2.1.8 Why is “lean” important?

Lean pursues profit maximization by reducing costs, in addition to that the concept focuses on the elimination of non-value-adding process components and thus reduces costs in a sustainable and competitive manner. The customer is the focus. A company can only be successful on a long term if it is customer oriented. The goal of lean is to achieve 100% customer satisfaction at the lowest possible cost. (Bertagnolli, 2018)

This is only possible, if the core elements of Lean Management are fully implemented. One of these elements is Kaizen. Kaizen is a Japanese philosophy which is not only relevant for any kind of a management field, it is valid for the daily life. It means to make continuous progress, increase efficiency and improvements in any area. In the west it is translated as continuous improvement. Continuous improvement is associated with several management methods, but in general it is a company-wide process of focused and continuous incremental improvements out of the center of Lean Management. Small changes done from every person, every day in an organization to generate better processes, less waste, more value and a better place to work. (Singh & Singh, 2015)

The basic idea of lean thinking comes from the manufacturing sector. However, this is only a small part of a company where Lean Management can be applied. In summary, it can be said that every area, every person in a company can apply Lean Management.

The decisive factor for the success of the methods is that this is also ensured. Only then is the effectiveness most likely and most efficient.

2.2.2 Lean methods

Lean Management encompasses a diverse array of tools and methodologies, the exhaustive enumeration of which exceeds the intended scope of this study. Recognizing this, a judicious selection process has been undertaken, resulting in the identification and elucidation of 21 key methods, as detailed in Table 4. The rationale behind this selection hinges upon the prevalence of these methods within the extant literature, with higher frequencies of citation corresponding to heightened prominence within the table. While it is acknowledged that not every conceivable tool has been exhaustively covered, it is posited that the collection presented here encapsulates the most salient and frequently referenced methodologies. Moreover, it is pertinent to note that the significance of each method within the context of this study has also been duly considered in the selection process. Consequently, the ranking presented in Table 4 is a synthesis of both frequency of occurrence and contextual relevance, thereby furnishing a comprehensive overview of the most pivotal Lean Management tools for the purposes of this research endeavor.

Table 4: Most common lean methods

Lean method	**Level of occurrence (high, mid, low)**	**Description**
JIT - just in time (Hirano, 2009) (García-Alcaraz et al., 2019) (Pinto et al., 2018) (Ward & Zhou, 2006)	High	JIT is a lean manufacturing and inventory management system that aims to minimize waste and increase efficiency by producing or delivering products and materials just in time when they are needed in the production process. In a JIT system, production is synchronized with demand, so that materials and components are delivered to the production line only when they are needed. As a result, finished products are produced only in the required quantity and at the right time. This approach reduces the need for large inventories, which can be costly and wasteful, and enables companies to respond quickly to changes in demand and market conditions. This method was developed in Japan in the 1970s by Toyota and has since been adopted by many other companies around the world. JIT is often associated with other lean manufacturing practices such as Total Quality Management (TQM), Continuous Improvement (CI), and Value Stream Mapping (VSM). JIT can bring several benefits to companies, such as reduced inventory costs, improved quality and efficiency, faster production times, better customer service, and increased flexibility and responsiveness to changes in demand. However, implementing a JIT system can be challenging, as it requires close coordination and communication between suppliers, production teams, and other stakeholders, as well as a culture of continuous improvement and waste reduction.

TQM - total quality management (Oakland, 2014) (Dhillon, 2002) (Andersson et al., 2006) (Dahlgaard & Mi Dahlgaard-Park, 2006)	High	Total Quality Management is a management philosophy that emphasizes the continuous improvement of processes, products, and services to meet or exceed customer expectations and achieve organizational objectives. TQM involves the active involvement of all employees in the organization in the pursuit of quality excellence. It encompasses a range of activities and practices, such as customer focus, process improvement, employee involvement, leadership, continuous learning, and innovation. Some of the key principles and techniques of TQM include: • Customer focus: The aim is to understand and meet the needs and expectations of customers by collecting and analyzing feedback and using this information to improve products and services. • Continuous improvement: TQM emphasizes the continuous improvement of processes, products, and services through the use of techniques such as Kaizen, Six Sigma, and Lean Manufacturing. • Employee involvement: TQM recognizes that employees are a valuable source of knowledge, innovation, and encourages their participation in problem-solving and decision-making processes. • Leadership: It requires a strong leadership commitment and involvement in promoting a culture of quality and setting clear objectives. This focuses on the secured provision of the necessary resources and support for continuous improvement. • Process management: TQM emphasizes the importance of effective process management to ensure

		consistent and reliable performance, and to identify and address any sources of variation or waste. Possible benefits to organizations by applying this method are improved customer satisfaction, increased efficiency and productivity, reduced costs and waste, better employee morale and engagement, and enhanced competitiveness and reputation. However, implementing TQM requires a long-term commitment and a willingness to change organizational culture and practices, which can be challenging for some firms.
5S (Monden, 2012) (Bevilacqua et al., 2019) (Chandrayan et al., 2019) (Filip & Marascu-Klein, 2015) (Gomes et al., 2013)	High	5S is a workplace organization and housekeeping methodology that originated in Japan and is a quite important part in lean manufacturing. The methodology involves five steps, each of which begins with the letter S: • Sort (seiri): The first step is to sort through everything in the work area and remove any unnecessary items. This helps to eliminate clutter and create a more organized and efficient workspace. • Set in order (seiton): Once unnecessary items have been removed, the next step is to organize the remaining items in a way that makes them easy to find and use. This might involve labeling or color-coding items, arranging them in designated storage areas, or using visual management tools such as shadow boards. • Shine (seiso): The third step is to clean and inspect the work area to ensure that everything is in good working condition and free of dirt and debris. This helps to maintain a safe and healthy work environment and

		prevent equipment breakdowns or defects. • Standardize (seiketsu): The fourth step is to establish standardized procedures and work instructions for maintaining the work area, such as cleaning schedules or visual controls. This helps to ensure consistency and reliability in the workplace and prevent mistakes or deviations from established standards. • Sustain (shitsuke): The final step is to maintain the gains made in the previous steps by regularly reviewing and improving the 5S system. This involves training employees, conducting audits or inspections, and making adjustments as needed to ensure that the system continues to function effectively over time. The benefits of 5S include improved workplace organization, increased productivity and efficiency, reduced waste and defects, improved safety and quality, and enhanced employee engagement and morale. 5S is also an important foundation for other lean tools and methodologies.
VSM - value stream mapping (Oakland, 2014) (Voehl, 2013) (Abdulmalek & Rajgopal, 2007)	High	Value stream mapping is a lean manufacturing technique used to analyze and improve the flow of materials and information through a manufacturing or service process. It is a visual tool that helps identify waste and inefficiencies in a process by highlighting opportunities for improvement. A value stream map is a flowchart that shows the steps in a process, from customer order to delivery of the finished product or service. The map includes information on the time required to complete each step, the inventory levels at each step, the flow of materials and information, and any

(Forno et al., 2014) (Seth * & Gupta, 2005) (Kumar et al., 2018)		bottlenecks or delays in the process. The purpose is to identify and eliminate non-value-added activities, such as overproduction, waiting, excess inventory, unnecessary transportation, overprocessing, defects, and unused employee talent. By doing so, organizations can reduce lead time, increase productivity, improve quality, and reduce costs. To create a value stream map, a team of employees from different functional areas work together to observe and document the process. Following is an analysis of the data, which identifies opportunities for improvement. From the result, an action plan is created, which in terms of implementation can have the following effects on a company: • Identifying waste and inefficiencies in the process. • Highlighting opportunities for improvement and cost savings. • Providing a visual representation of the process that can help employees better understand and communicate about the process. • Facilitating cross-functional collaboration and communication. • Creating a culture of continuous improvement by encouraging employees to identify and solve problems. Value stream mapping can be applied to many different types of processes, from manufacturing to service delivery. It is an important tool for companies seeking to improve their operations and to increase customer satisfaction.

7 wastes - Seven types of waste (Voehl, 2013) (Smalley, 2010) (Hernadewita et al., 2019) (Zhang et al., 2014)	High	In Lean Management different types of waste are defined. Muda, Mura and Muri are Japanese terms, which show the big picture of possible root causes of waste. Muda means waste, Mura means inconsistency and Muri can be seen as irrationality. These three terms are theoretical differentiations, which are not needed in the field of applications. Irrationality (Muri) and inconsistency (Mura) always results in waste (Muda) in practice. As a result, there are seven types of waste defined as the following: • Overproduction: Producing more than is needed or producing too early, which results in excess inventory, unnecessary work, and wasted resources. • Waiting: Idle time, delays, or downtime caused by inefficient processes or lack of coordination between departments. • Transportation: Unnecessary movement or handling of materials or products, which increases lead time and the risk of damage or loss. • Processing: Overprocessing or performing unnecessary steps in a process that do not add value to the product or service. • Motion/operation related: Unnecessary movement of people or equipment, which can cause strain or fatigue and increase the risk of accidents or injuries. • Inventory: Excess inventory that ties up capital, increases storage costs, and increases the risk of obsolescence or waste. • Defects: Products or services that do not meet customer requirements or have quality problems,

		which result in rework, waste, and lost productivity. By identifying and eliminating these types of waste, companies can reduce lead time, increase productivity, improve quality, and reduce costs. The goal is to create a lean and efficient production process that focuses on delivering value to the customer while minimizing waste.
FMEA - failure mode and effects analysis (Oakland, 2014) (Bhuvanesh Kumar & Parameshwaran, 2018) (Victor B. de Souza & Cesar R. Carpinetti, 2014) (Sutrisno et al., 2018)	High	FMEA stands for Failure Mode and Effects Analysis. It is a systematic approach used to identify and prevent potential failures in a product or process before they occur, by evaluating and highlighting their potential effects. This process-oriented approach includes the following steps: • Identify potential failure modes: The first step is to identify all the potential failure modes in the product or process. • Assess the severity of the failure: For each failure mode, determine the severity of the potential effects on the product or process, the customer, or the environment. • Identify the causes of the failure: Identify the potential causes of the failure mode. • Assess the likelihood of occurrence: Determine the likelihood that the failure mode will occur. • Evaluate the current controls: Assess the effectiveness of the current controls that are in place to prevent or detect the failure mode. • Determine the risk priority number (RPN): Calculate the RPN by multiplying the severity, likelihood, and detection ratings.

		• Identify and prioritize corrective actions: Develop and prioritize corrective actions to address the high-risk failure modes.
		• Implement the corrective actions and monitor their effectiveness to ensure that they are addressing the failure modes.
		• The benefits of using FMEA include:
		    • Identifying potential failure modes before they occur.
		    • Prioritizing corrective actions based on the severity, likelihood, and detection rating.
		    • Reducing the risk of product or process failures.
		    • Improving product or process design and quality.
		    • Increasing customer satisfaction and confidence.
		    • Reducing costs associated with warranty claims, recalls, and rework.

Six Sigma (Arnheiter & Maleyeff, 2005) (Albliwi et al., 2015) (Snee, 2010) (Drohomeretski et al., 2014)	High	Six Sigma is a data-driven, structured approach to process improvement that aims to reduce variability and defects in a process, product, or service. It is a methodology that uses statistical analysis and other tools to identify and eliminate defects, errors, or waste in a process, and to improve customer satisfaction. The term "Six Sigma" refers to the goal of achieving a process performance level that has a defect rate of 3.4 defects per million opportunities, which equates to 99.99966% quality level. This high level of quality is achieved by using a structured approach, called DMAIC, which stands for Define, Measure, Analyze, Improve, and Control.

		Following steps are defined:
		
		• Define: Define the problem, project goals, and customer requirements.
		• Measure: Collect and analyze data to measure the current process performance and identify areas of improvement.
		• Analyze: Analyze the data to identify the root cause(s) of the problem or variability in the process.
		• Improve: Develop and implement solutions to address the root cause(s) and improve the process.
		• Control: Monitor and control the process to ensure that the improvements are sustained and that the process performance meets the desired level of quality.
		• The benefits of using Six Sigma include:
		    • Improved quality and customer satisfaction.
		    • Reduced defects, errors, and waste.
		    • Increased productivity and efficiency.
		    • Reduced costs associated with rework, scrap, and warranty claims.
		    • Improved employee engagement and morale.
		    • Enhanced organizational reputation and competitiveness.
		
		Six Sigma can be applied to many different types of processes, from manufacturing to service delivery, and can be used in any industry or sector.

Kaizen / CIP continuous improvement process (AL-Tahat & Jalham, 2015) (Berger, 1997) (Chiarini et al., 2018) (Doolen et al., 2008) (Modarress et al., 2005) (Paul Brunet & New, 2003) (Styhre, 2001)	High	Kaizen, which means "change for the better" in Japanese, is a continuous improvement philosophy that aims to improve processes, products, or services incrementally over time. It is a key component of the Lean Management methodologies. It is based on the principle that small, gradual improvements made consistently over time can lead to significant overall improvement in a process or system. It involves a systematic approach to problem-solving, focusing on identifying and eliminating waste and improving efficiency. Following steps are defined: • Identify the problem or opportunity for improvement. • Analyze the current process to identify the root cause(s) of the problem or waste. • Develop and implement solutions to address the root cause(s). • Evaluate the results to determine the impact of the improvement. • Standardize the new process to ensure that the improvements are sustained over time. • Continuously monitor and improve the process to identify new opportunities for improvement. Continuous Improvement Process (CIP) is a similar approach to Kaizen that is used to continually improve a process, product, or service. It is a structured and systematic approach to identify and eliminate waste and improve efficiency, quality, and customer satisfaction. CIP is based on the principle that improvement is an ongoing process that requires continuous monitoring, evaluation, and

		refinement. It involves a cycle of four steps: Plan, Do, Check, and Act (PDCA), those steps are:
		• Plan: Identify the problem or opportunity for improvement and develop a plan to address it.
		• Do: Implement the plan and monitor the results.
		• Check: Evaluate the results to determine if the improvement was successful.
		• Act: Standardize the new process and continue to monitor and improve it over time.
		• The benefits of using Kaizen or CIP include:
		  o Improved quality and customer satisfaction.
		  o Increased productivity and efficiency.
		  o Reduced defects, errors, and waste.
		  o Improved employee engagement and morale.
		  o Reduced costs associated with rework, scrap, and warranty claims.
		  o Enhanced organizational reputation and competitiveness.

VC - Visual control system via KPIs (key performance indicator) (Monden, 2012) (Helmold,	Mid	A visual control system via KPIs is a method of tracking and analyzing the performance of a business or organization using visual aids such as graphs, charts, and dashboards. KPIs are specific metrics that are used to measure the progress of an organization towards its goals. By tracking KPIs visually, stakeholders can quickly and easily see how well the organization is performing. To create a visual control system via KPIs, organizations should follow these steps: • Identify the relevant KPIs for the organization. These should be metrics that are aligned with the

2020) (Kovalevsky et al., 2021) (Mourtzis et al., 2018) (Zhao et al., 2022)		organization's goals and objectives. • Determine how to measure and track the KPIs. This may involve setting up systems to collect and analyze data, such as using software programs or spreadsheets. • Create visual aids to display the KPI data. This can include charts, graphs, and dashboards that are updated in real-time to reflect the latest data. • Determine how often to review and update the KPI data. This may be on a daily, weekly, or monthly basis depending on the needs of the organization. • Use the visual control system to identify trends and patterns in the data to make informed decisions about the organization's performance. By implementing a visual control system via KPIs, organizations can gain a better understanding of their performance and make more informed decisions. This can lead to improved productivity, increased efficiency, and ultimately, greater success in achieving organizational goals.
OEE - overall equipment effectiveness (Voehl, 2013) (Roriz et al., 2017) (Avila-Pisco et al.)	Mid	The Overall Equipment Effectiveness is a metric used to measure the efficiency of equipment or machinery in manufacturing or production processes. OEE provides a way to identify and quantify losses in production and helps companies to identify areas of improvement. It is calculated by multiplying three metrics: • Availability: The percentage of time that the equipment is available for production. This includes planned and unplanned downtime. • Performance: The rate at which the equipment is

(Chiarini, 2015)
 	
(Gibbons & Burgess, 2010)
 	
(Haddad et al., 2021)
		producing units compared to its maximum capacity.
		• Quality: The percentage of units produced that meet quality standards.
		• The formula for calculating OEE is:
		  • OEE = Availability x Performance x Quality
		  • For example, if a machine has an availability of 88%, a performance rate of 84%, and a quality rate of 92%, its OEE would be: OEE = 0.88 x 0.84 x 0.92 = 0,680064 or 68%
		
		A result of 100% means that the equipment is producing units at its maximum capacity with no downtime and no quality issues. However, achieving 100% OEE is often not possible, and companies typically set targets based on their industry benchmarks. By using this tool for evaluation of equipment, companies can identify the root causes of inefficiencies and losses in production and take steps to improve their processes, which results in an increase of productivity, reduction in costs and improvement of the quality of the produced products.

SMED - single minute exchange of die (Roriz et al., 2017) (Junior et al., 2022)	Mid	SMED stands for Single Minute Exchange of Die, which is a methodology used in manufacturing to reduce the time it takes to change over a production line from one product or process to another. The goal of this method is to minimize the amount of time that is wasted during these changeovers, as well as to improve overall efficiency and productivity. The SMED methodology was developed by Shigeo Shingo, a Japanese industrial engineer, as part of the Toyota Production System. The approach focuses on breaking down changeover tasks into smaller, more manageable steps and then working

(Nikolic et al., 2023) (Singari et al., 2023)		to eliminate or simplify those steps to reduce the overall time required. Some of the key principles of SMED include: • Separating internal and external setup activities to minimize downtime. • Converting setup activities to be performed while the machine is still running. • Standardizing setup procedures to eliminate variations and improve efficiency. • Using visual controls to improve communication and reduce errors. By implementing SMED, companies can reduce the time it takes to change over production lines, which can lead to increased productivity, lower costs, and improved customer satisfaction.
TPM - total productive maintenance (Hirano, 2009) (Crosby & Badurdeen, 2022) (Lorenz & König, 2011)	Mid	Total Productive Maintenance is a manufacturing strategy that aims to maximize the productivity and reliability of equipment by involving all employees in the maintenance process. TPM focuses on ensuring that equipment is always in good working condition, which results in a sustainable product quality. Additional benefit is a reduction of downtimes and an increase of the overall efficiency. TPM is based on the idea that all employees, from operators to maintenance technicians, are responsible for maintaining equipment and ensuring its optimal performance. The approach involves regular inspections, cleaning, and lubrication of equipment, as well as preventative maintenance

(McCarthy, 2015) (Sekine & Arai, 2017)		to prevent breakdowns. Some of the key principles of TPM include: • Focusing on proactive, preventative maintenance to minimize downtime. • Involving all employees in the maintenance process, regardless of their role. • Standardizing maintenance procedures to ensure consistency and efficiency. • Using data and analytics to monitor equipment performance and identify areas for improvement. • Providing training and support to employees to ensure they have the skills and knowledge necessary to perform maintenance tasks effectively. Summing up, companies can improve equipment reliability and performance, reduce downtime and maintenance costs, and increase overall productivity and efficiency by implementing TPM. Additionally, it can help to create a culture of continuous improvement by involving all employees in the maintenance process and encouraging them to identify and address issues before they become problems.
Kanban (Krieg, 2005) (Lage Junior & Godinho Filho, 2010)	Mid	Kanban is a lean manufacturing and project management methodology that is designed to improve the flow of work and the reduction of waste. The term "Kanban" is Japanese for "visual signal" or "card," which refers to the physical cards that are used to track the progress of tasks in the system. These tasks are represented by cards or sticky notes that are placed on a Kanban board. The board is typically divided into

(Lee-Mortimer, 2008) (Sugimori et al., 1977)		columns that represent different stages of the workflow, such as "Backlog", "In Progress," and "Done." Each column has a limit on the number of cards that can be in that column at any given time, which helps to prevent overloading and improve flow. Some of the key principles of Kanban include: • Visualizing the workflow to make it easier to understand. • Limiting work in progress to improve flow and reduce multitasking. • Managing work using a pull system, where tasks are pulled from one stage to the next as capacity allows. • Continuously improving the system by analyzing performance data and making changes as needed. Kanban can be used in a wide range of industries and applications, from manufacturing and software development to marketing and healthcare. It is particularly useful in situations where teams are facing a lot of variability or uncertainty in the work process, as it allows them to adapt quickly to changing requirements or priorities. By implementing Kanban, teams can improve collaboration, increase productivity, and deliver higher quality results.
QFD - quality function deployment (Morel-Guimaraes et al., 2005)	Mid	QFD stands for Quality Function Deployment, which is a methodology used in product design and development to ensure that customer requirements are translated into specific product features and characteristics. The goal of QFD is to create a product that meets or exceeds customer expectations and needs.

(Voehl, 2013) (Govers, 1996) (Mohanraj et al., 2011)		The QFD process involves several key steps: • Voice of the Customer: Identifying and analyzing customer needs and expectations through market research, surveys, and other feedback mechanisms. • Product Planning: Defining the product requirements and identifying the key features and characteristics that are necessary to meet customer needs. • Product Design: Developing the detailed design specifications and engineering plans that are required to bring the product to life. • Process Planning: Identifying the manufacturing and production processes that are necessary to produce the product. • Production: Implementing the manufacturing and production processes and ensuring that the product is produced to the required quality standards. • Customer Feedback: Collecting feedback from customers to ensure that the product is meeting their needs and expectations. Important is to implement possible improvements as necessary. By following the QFD process, companies can ensure that their products are designed and developed with a strong focus on meeting customer needs and expectations. This can lead to higher customer satisfaction, increased sales, and improved product performance and quality.

<table>
<tr>
<td>Poka Yoke

(Saurin et al., 2012)

(AL-Tahat & Jalham, 2015)

(Wedgwood, 2016)

(Puvanasvaran , 2014)</td>
<td>Mid</td>
<td>Poka Yoke is a Japanese term that translates to "mistake-proofing." It is a methodology used in manufacturing and other industries to prevent errors or defects from occurring. Poka Yoke involves several key principles:

Prevention: Rather than correcting mistakes after they occur, Poka Yoke focuses on preventing mistakes from happening in the first place.
Simplification: It seeks to simplify processes and reduce complexity, in order to reduce the likelihood of errors.
Standardization: By standardizing processes and procedures, Poka Yoke makes it easier to identify deviations and correct errors.
Attention to detail: Poka Yoke involves a high level of attention to detail to identify potential sources of error and implement preventative measures.
Examples of Poka Yoke include:

Visual cues: Using color coding or labeling to make it clear which components should be used in a particular process.
Physical cues: Using physical shapes or mechanisms to prevent errors, such as using a key that only fits into the correct slot. The special shape of a component does not allow incorrect assembly.
Process controls: Using automated processes or checklists to ensure that each step in the process is completed correctly.

</td>
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</table>

		Reduction of the likelihood of errors or defects in products is the main target of Poka Yoke, this is leading to higher quality and greater customer satisfaction.
Jidoka (Hirano, 2009) (Deuse et al., 2020)	Mid	Jidoka enables production processes/machines to run autonomously. To make such a case possible that no human assistance or supervision is necessary anymore, the equipment needs to fulfill high requirements. The Jidoka principle provides a procedure to get to this point of no human input is needed anymore. This is not a one-step process. It is divided into three main functions: 1. Separation of human work from machine work 2. Development of defect-prevention devices 3. Application of Jidoka to assembly operations Jidoka is based on the idea that machines should be designed to stop automatically when a problem occurs, rather than allowing defects to continue to be produced. In addition to improving product quality, Jidoka can also help to increase efficiency by reducing waste and downtime. By giving operators the responsibility and authority to stop the production process when a problem occurs, Jidoka encourages continuous improvement and helps to create a culture of problem-solving and innovation within the organization.

ABC material handling (Goldsby & Martichenko, 2005) (Alsmadi et al., 2014) (Hadid, 2019)	Low	ABC material handling refers to a technique used in inventory management to categorize items based on their value and frequency of use. This technique helps companies to prioritize their inventory items and allocate resources more efficiently. It determines the most efficient storage and handling methods for different categories of items. For example, A items may be stored in a location that is easily accessible and close to the production area, while C items may be stored in a less accessible area to save space and reduce handling costs. This method supports the reduction of different types of waste, like described above. It is divided into three types of stock: • A items: These are high-value items that are typically used frequently. They represent a small percentage of the total inventory, but account for a large percentage of the overall value. • B items: These are medium-value items that are used less frequently than A items. They represent a larger percentage of the inventory than A items, but a smaller percentage of the overall value. • C items: These are low-value items that are typically used infrequently. They represent a large percentage of the inventory, but a small percentage of the overall value. By categorizing inventory items into these groups, companies can focus their resources on managing the most valuable and frequently used items, while minimizing the amount of time and resources spent on less valuable or infrequently used items.

Five Whys (Voehl, 2013) (Goldsby & Martichenko, 2005) (Barsalou et al., 2024)	Low	The Five Whys is a problem-solving technique used to identify the root cause of a problem or issue. It is a simple and effective approach that involves asking "why" five times to uncover the underlying cause of a problem. Process description: • Identify the problem: Start by clearly defining the problem or issue you want to address. • Ask "why" the problem occurred: Ask why the problem occurred and identify the immediate cause of the issue. • Repeat the question "why" four more times: For each answer, ask "why" again, to uncover the underlying cause of the problem. Continue asking "why" until you have identified the root cause of the issue. • Address the root cause: This may involve implementing a solution to prevent the problem from recurring, or making changes to the process or system to eliminate the root cause. The Five Whys technique can be used in a variety of contexts. It is a simple and effective way to get to the bottom of a problem and identify the underlying cause, rather than just treating the symptoms.

Pareto chart (Craft & Leake, 2002) (Ilyasse K. & Moulay O. A., 2023) (Goldsby & Martichenko, 2005)	Low	A Pareto chart is a visual tool used to identify the most significant factors contributing to a problem or issue. It is based on the Pareto principle, which states that 80% of the effects come from 20% of the causes. The Pareto chart is a bar graph that displays the frequency or relative importance of each cause or factor, arranged in descending order of significance. The left axis represents the frequency or percentage of each cause, while the right axis represents the cumulative percentage of the causes. The Pareto chart helps to identify the most important or frequent causes of a problem or issue to prioritize them for further analysis or action. It can be used to identify trends, patterns, and outliers in data to visualize the impact of different factors on the overall problem. To create a Pareto chart, follow these steps: • Identify the problem or issue to be analyzed. • Identify the potential causes or factors contributing to the problem. • Collect data on the frequency or impact of each cause or factor. • Rank the causes in descending order of frequency or impact. • Create a bar graph with the causes on the x-axis and the frequency or impact on the y-axis. • Add a cumulative percentage line to the graph. • Analyze the graph to identify the most significant causes and prioritize them for further analysis or action. The Pareto chart supports in finding, identifying, and addressing the most important causes of a problem.

TOC - Theory of Constraints (Goldratt, 1990) (Alsmadi et al., 2014) (Rahman, 1998) (Shaaban & Darwish, 2016) (Watson et al., 2007)	Low	The management philosophy that was developed by Dr. Eliyahu Goldratt in the 1980s. It is a systematic approach to identifying and managing constraints to improve the overall performance of a system. The core idea of the TOC is that every system has at least one constraint, which limits the system's ability to achieve its goals. The constraint can be physical, such as a machine or process, or non-physical, such as a policy or decision-making process. The TOC aims to identify the constraint(s) and then focus on managing them to improve the overall system performance. The TOC has five main steps: • Identify the system's constraints • Decide how to exploit the constraints to maximize performance • Subordinate everything else to the above decision • Elevate the constraints if the performance is still not improved/good • Repeat the process to continuously improve the system's performance The TOC is widely used in manufacturing, supply chain management and project management, in different industries. It provides a systematic way of thinking about problems and opportunities and helps organizations to focus their efforts on the areas that will have the greatest impact on performance.

Gemba (Kihn, 2012) (Cherrafi et al., 2019) (Liu & Goh, 2015)	Low	Gemba is a Japanese term that refers to the place where work is done, such as a factory floor or an office. It is the place where the actual work is being done, and where the problems and opportunities for improvement can be observed firsthand. The Gemba approach is a key part of the lean philosophy, which emphasizes the importance of continuous improvement and the elimination of waste. By going to the Gemba, managers and quality professionals can see firsthand how processes are working and can identify opportunities for improvement that might not be apparent from other sources. Lean thinking is not a natural thing for people, that is why it is necessary to change the behavior. It is counter-intuitive and counter-cultural to change processes because we are used to what we think is the right and natural way to do things. To reinforce lean thinking is to do Gemba walks. Gemba is a Japanese term which describes the place, where value is added. At this places questions should be asked for getting a deep understanding of the value creation process. Additionally, employees also get a better understanding of the actual goal of their work during those discussions. The approach is not limited to manufacturing and can be applied in a variety of industries and settings. Overall, it is a valuable tool for continuous improvement actions and can help organizations to identify and address problems.

2.2.3 Summary of Lean Management

Lean Management is a widely studied approach to organizational and operational excellence. Originating from Toyota Production System, it focuses on reducing waste and improving efficiency. The objective of the review above is to provide an overview of key concepts, methods, and recent trends in Lean Management research. Central to Lean Management is the concept of Muda, which involves identifying and eliminating various forms of waste in processes, such as overproduction, defects, inventory, and unnecessary motion. Kaizen emphasizes the importance of ongoing, incremental improvements in processes, products, and services through the involvement of all employees. Lean Management emphasizes the respect for employees' knowledge, skills, and contributions, fostering a culture of collaboration, empowerment, and employee involvement.

Lean philosophy, initially rooted in manufacturing, has found broad application across sectors like automotive, aerospace, and electronics. Its primary aims include optimizing production, minimizing defects, and enhancing efficiency. Implementing lean tools often necessitates a cultural shift within organizations, which may encounter resistance from employees accustomed to conventional practices. Striking a balance between lean's efficiency objectives and sustainability/environmental considerations presents a significant challenge. Additionally, applying lean principles in complex, non-repetitive processes or highly variable environments can provide a distinct advantage.

The integration of lean principles with Industry 4.0 technologies (IoT, AI, automation) will be a key focus, enabling data-driven process improvements and real-time decision-making. Furthermore, Lean Management will continue to evolve with a stronger emphasis on sustainable practices, aligning with global environmental goals. For instance, the COVID-19 pandemic has reshaped work environments, making Lean Management vital for adapting to new realities. It will reach beyond operations into other functional areas like marketing, sales, product development and Technology Management.

In conclusion, Lean Management remains a powerful approach for organizations seeking to improve efficiency and eliminate waste by constantly adopting to changing business landscapes and challenges. Researchers and practitioners in the field should stay informed about the latest developments and trends to effectively apply lean principles in their organizations.

2.3 Technology Management

Technology Management can be seen as a part of corporate management. The central point of Technology Management is here the securing and strengthen of a company's competitiveness. This is assured by a targeted change of a product technology or manufacturing technology by providing the needed information about a technology in case of implementation, resources and costs. (Schuh & Klappert, 2011) To ensure the competitive advantage and growth through Technology Management, technological considerations have to be integrated into corporate processes. This challenging task requires incorporation of various units within a firm, like R&D, production, business fulfilment, HR and finance. In addition to that, Technology Management requires both strategic and operational issues. This results in strategic considerations and actions for implementation and renewal. To support these needed activities, several similar frameworks are available to structure the whole Technology Management process. (R.Phaal et al., 1998) In other words, major clusters of Technology Management are the recognition of opportunities to leverage technology, protection of knowledge, technology trajectories, innovation activities, internal as external influences, systematic capture of knowledge, overlapping of key functions etc. However, those mentioned clusters need to be taken into account to have a functional Technology Management in a firm. (M.J. Gregory, 1995) Technology will continue to transform the business environment in significant ways. The ongoing digitalization of business processes and the rise of artificial intelligence and machine learning will create new opportunities and challenges for organizations. As technology becomes increasingly complex, collaboration between technology and business personnel will become more critical.

Effective Technology Management will require cross-functional teams that can work together to develop and implement technology solutions. Moreover, agile management practices, which emphasize flexibility and adaptability, will become more important as organizations seek to respond to rapidly changing technology and business environments. As a result, to stay competitive strategic thinking and an understanding of the broader business context is crucial for success. Technology managers will need to think beyond technology solutions and understand how technology can be used to create value for the organization. However, care must be taken to ensure that ethnic and social principles are observed. As technology becomes more pervasive in society, ethics and social responsibility will become increasingly important for technology managers. Organizations will need to consider the ethical implications of their technological solutions and ensure that they are aligned with their values and goals in the area of social responsibility. (Marcus, 2016)

In the following chapters 2.3.1 Definition and understanding, various definitions of Technology Management are presented in detail and the associated principles and methods are explained. Subsequently, chapter 2.3.2 Principles, methods and tools carefully analyses the various aspects of the above-mentioned principles, methods and tools in the field of Technology Management. Conclusively, Chapter 2.3.3 Summary of Technology Management, succinctly encapsulates the overarching theme.

2.3.1 Definition and understanding

For a better understanding, the terms technology and technique will be described shortly. Moreover, the differentiation to the term innovation will be shown. Technology is interpreted in the narrower sense as scientifically based knowledge that describes target relationships/means relationships. These can consequently be applied in companies to solve practical problems. Furthermore, technique is defined as the application of various technologies for materialized products and processes. The focus is on the solution of specific practical problems in companies. From a business perspective, innovation for a company is described as the intention to improve its own position in the trading environment. From the company's point of view, this applies to both internal and external improvements. This result-oriented view can be divided into further differentiations of innovations, such as differentiation according to the innovation object, the degree of innovation as well as according to the novelty property. (Gerpott, 2005) However, these degrees will not be described further here and are only intended to serve as an explanation of the terms.

Technology Management can be seen as a cross-sectional function between technology and management. This results in adjacent and partly overlapping topics, the most important are innovation management and R&D management. That is why, it is important to distinguish between Technology Management, R&D management and innovation management. Technology Management focuses on the creation and utilization of technologies. On the one hand, this takes into account the new and further development and, on the other hand, the application of technologies throughout the entire technology life cycle. Innovation management focuses on product development processes and market introduction processes, whereby the innovation relates to products, processes, organizational forms or even new technologies. In research and development, the focus is clearly on acquiring new knowledge as well as applying it for the first time. (Schuh & Klappert, 2011)

Overall, effective Technology Management requires a strategic approach that focuses on aligning technology with business goals, managing technology as a tool, and fostering a culture of innovation. Some of the most important thoughts, ideas for a successful Technology Management in companies are to see technology as a tool, not as a solution. That means that Technology Management requires a clear understanding of the organization's goals and how technology can be used to support them. Next, there has to be a connection or alignment with the business strategy. That signifies a clear understanding of technology to be able to contribute to the organization's overall objectives. Further, Technology Management is about people, not just technology. It requires skilled and experienced personnel who can manage technology projects and resources. Finally, Technology Management should be approached strategically, with a focus on long-term goals rather than short-term fixes. Organizations should have a clear technology strategy that is aligned with their overall business strategy. (Drucker, 1970)

In the following Table 5 definitions of Technology Management are listed from different authors.

Furthermore, in the subsequent chapters, a more detailed exploration of technology categorizations is undertaken. Specifically, in Chapter 2.3.1.1 Classification of Technologies, the classification of technologies is expounded upon. This is succeeded by an examination of technology lifecycles in Chapter 2.3.1.2 Technology Lifecycle. The conclusion is encapsulated in Chapter 2.3.1.3 Diffusion of Technologies, which delves into the dissemination and adoption of technologies.

Table 5: Overview of selected articles providing definitions for Technology Management. Articles are sorted by date of publication.

Author	**Type**	**Year of publication**	**Definition of Technology Management**
Drucker	Book	1970	Technology Management can be seen as a strategic approach, which has to be aligned with the company's goals on a long-term. Additionally, technology is not the solution, it is just the tool to ensure company's competitiveness. That is why skilled and experienced people are key to an effective Technology Management. (Drucker, 1970)
Martino	Book	1993	Technology Management is a key resource of fundamental importance for profitability and long-term growth. The main task is to link science, engineering, and management disciplines to issues involved in technology planning, development, and assessment to accomplish strategic and operational targets of a company. It

			is about integrating the technology strategy within the business strategy, which has an impact on the company as whole. (Martino, 1993)
Gregory	Article	1995	Technology Management is an important transducer for setting up a company's strategy. There is a clear need to understand the potential of new and existing technologies by implementing them in the strategy. Technology Management is the connecting link between R&D and innovation management by improving the technological competitiveness of a company. (M.J. Gregory, 1995)
Phaal & Paterson & Probert	Article	1998	Technology Management can be seen as a resource within a company that ensures the knowledge flow between commercial and technical functions. Furthermore, all activities out of Technology Management are linked to the three core business processes, like innovation, operations and strategy. (R.Phaal et al., 1998)
Specht & Gabler	Book	2002	In a broader sense, Technology Management can be defined as the planning, organization, realization and control of the knowledge about technologies that is required or already available in a company for the creation of products, production processes, control processes from a market perspective point of view. In addition, the

			relation between technology, civilization and culture is considered in terms of a political impact analysis (cultural lag). (Specht, 2002)
Dhillon	Book	2002	Managing of technologies to achieve business targets by focusing on required skills to be able to understand technology in combination with business activities. Some key factors to deal with for an effective Technology Management are the rapidly changing environment, limited available resources, increasing complexity, multifunctional teams, date-driven schedules, resource competition, limited rewards, uncertainty, and risks. (Dhillon, 2002)
Tesar	Book	2003	Technology Management is shaping the competitive landscape of industries, it is crucial for a company's competitive advantage. The philosophy is used to create disruptive or innovative products, services or business models by improving the efficiency and reduction of costs. The key theme of a company is to align the technology strategy with the business strategy, it is not a separate function, it should be embedded in all company processes. (Tesar, 2003)
Thamhain	Book	2005	Technology Management stands for a wide range of tasks, methods, tools and techniques, which consider the major disciplines of science,

			engineering, and management, by focusing on managing organizational processes and people affiliated with them. It includes the planning, organization, and integration of all resources needed to achieve the companies objectives. (Thamhain, 2005)
Gerpott	Book	2005	Technology Management is about planning, organizing, managing, and controlling activities and processes in a company to ensure the following: • Provision of new technologies • Use of these new technologies in products and processes • Exploitation of these new technologies, also via external partners In summary, this means that Technology Management should strengthen the company's position on the market sustainably and significantly (to a considerable extent) and contribute to improving its economic success. (Gerpott, 2005)
Morel-Guimaraes, Khalil, Hosni	Book	2005	Technology Management is the discipline that involves the application of management principles to technology-related activities. The major concern is to ensure a sustainable development within companies. Major tasks are the effective management of technology resources

			and their impact on the organization's overall performance and competitiveness. (Morel-Guimaraes et al., 2005)
Sherif	Book	2006	Technological change is shaping a company's development that is why Technology Management is one of the most important tasks within a company to sustain completive within its environment. One key activity is to collaborate and share knowledge with external partners and stakeholders to drive innovation. On top of that the role of government in promoting technological innovation is as important to ensure a pervasive acceptance of new technologies among the population. (Sherif, 2006)
Burgelman	Book	2009	Technology Management as a practical advice for managers supports to develop effective technology strategies, from identifying opportunities to building a culture of innovation within their organization. The key driver for innovation and competitive advantage is Technology Management, especially in fast-changing business environments. Furthermore, the role of leadership is important to create a culture that supports experimentation, risk-taking, and continuous learning. (Burgelman et al., 2009)

Schuh & Klappert	Book	2011	Technology Management can be seen as a part of corporate management. The central point of Technology Management is here the securing and strengthen of a company's competitiveness. This is assured by a targeted change of a product technology or manufacturing technology by providing the needed information about a technology in case of implementation, resources and costs. (Schuh & Klappert, 2011)
Schilling	Book	2013	To trigger innovation, an effective Technology Management within an organization is indispensable. The rapidly changing business environment postulates the understanding that the technology landscape is aligned with the organizational goals. Technology Management is a framework for analyzing the technology landscape, including identifying emerging technologies and assessing their potential impact on the industry. Furthermore, a collaboration as well as cross-functional teams are important to be and stay effective. (Schilling, 2013)
Marcus	Book	2016	Technology will rapidly continue changing the business environment. Consequently, Technology Management becomes more important than ever as a strategic approach to ensure long-term competitiveness. The focus is on experienced employees in conjunction with knowledge

	carriers in the respective industry. It is also important that the apparatus not only encompasses the development, implementation and profit generation from technologies, but that the focus is directed toward ethnic and social responsibility. (Marcus, 2016)

Table 5 shows different definitions of Technology Management, which can be summarized as follows. It can be clearly deduced that the different descriptions are united by the approach that Technology Management is part of corporate management. Schuh's framework shows how these areas of the company are influenced by Technology Management and how they are harmonized according to the technological goals as well as the company goals. This alignment of the technological goals with the overall corporate goals is an essential step for a successful implementation. Furthermore, the authors are of the opinion that long-term competitiveness can only be achieved if Technology Management is carried out effectively. Companies are required not to miss out on any opportunities but must be careful to assess risks wisely so as not to close any future doors. In order to avoid generating disadvantages in the rapidly changing environment, knowledge relationships and knowledge carriers are becoming increasingly important. The individual areas of Technology Management are described in the following chapters.

2.3.1.1 Classification of technologies

It is not always easy to rank technologies used in a company. To evaluate the importance of the technology for the future, it is necessary to classify it. As a result, recommendations can be advised to the management, by separating them via different criteria. (Schuh & Klappert, 2011) To gain a better basic understanding of the topic of Technology Management, it is important to know that there are different types of technologies defined. How these can be divided or classified is described in the following paragraph.

Field of application or function is one classification criterion. Here it can be separated in three sub areas, namely product, manufacturing or material technology. A product technology is used to fulfil the end customer's requirements for a specific product. The manufacturing technology is used to produce a product. It always depends on the view of the stakeholders, as a producer I am more interested in the manufacturing technology then in the product technology, here the user has the most interest in. In addition to that the material technology allows a higher quality, environmental capability or in general a fulfillment of higher requirements. Interdependencies are the next criteria. This criterion describes the collaboration of different technologies, it can be separated in single and system technologies. E.g., complex products exist out of several technologies, this is called system technology. Over and above, complementary and competing technologies are an additional criterion in the field of interdependencies. Complementary technologies supplement themselves by combining technologies to e.g., hybrid-technologies. In comparison to that, competing technologies can occur as just an alternative option or as a substitution. Depending on the usage of technologies in different industries, the separation criteria is called cross-sectional and special technologies. That means cross-sectional technologies are used for several industries and special technologies just for one concrete use case. Another criterion is to separate between core competence and support technologies. Core competence technologies are crucial for the company's long-term market competitiveness. Those technologies are hard to copy and cover the main market of the company. The most cases show a strong reference to manufacturing and product technologies. Support technologies are not that important for a company, this knowledge is organized via second source. (Schuh & Klappert, 2011)

2.3.1.2 Technology lifecycle

In terms of their relevance for a company, technologies are very strongly influenced by the time factor. This means that the priority of different technologies used in the company changes because they are in different life cycles. In other words, for the competitiveness of a company, this means that these technology life cycles must always be kept in mind. There are several models that address this issue. Two of these models are explained in the next paragraphs. The decisive advantage of such prognoses is that a company can define measures in time and no market-relevant trends are missed. Different degrees of development of technologies have an influence on strategic decisions and must be taken into account accordingly in the decision-making process. (Schuh & Klappert, 2011)

In Figure 5 the different stages of such a life cycle are visualized. The abscissa shows the cumulative R&D effort and the ordinate the performance and cumulative patent applications.

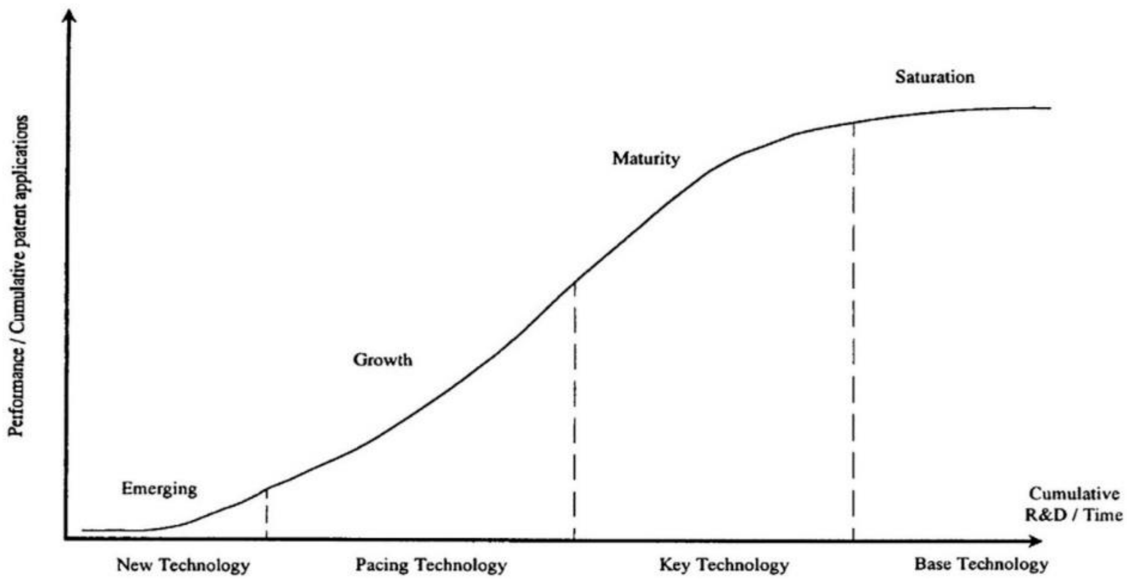

Figure 5: Technology life cycle (Gao et al., 2013, p. 399)

2.3.1.2.1 Hype cycle model from Gartner

The model shown in Figure 6 describes from a demand-related perspective, how technologies and applications develop over time. The expectation and the degree of interest in a technology, are set as dependent variables as a function over time. The achievable level of expectations or the degree of attention of a technology, depends on the size of the field of applicable possibilities. In addition to that it is assumed that the reaction on new technologies is mostly similar and the diffusion passes always the same phases, as described next: 1) Innovation trigger - first time of publication, technical feasibility outside of a circle of experts; 2) Peak of inflated expectations - increasing number of superficial articles lead to too high expectations; 3) Trough of disillusionment - a lot of projects fail, which results in an additional research need to the requirements of customers and investors; 4) Slope of enlightenment - deeper understanding of the technology and presentation of new generations of products and applications; 5) Plateau of productivity - higher performance results in increasing number of successful applications (Schuh & Klappert, 2011)

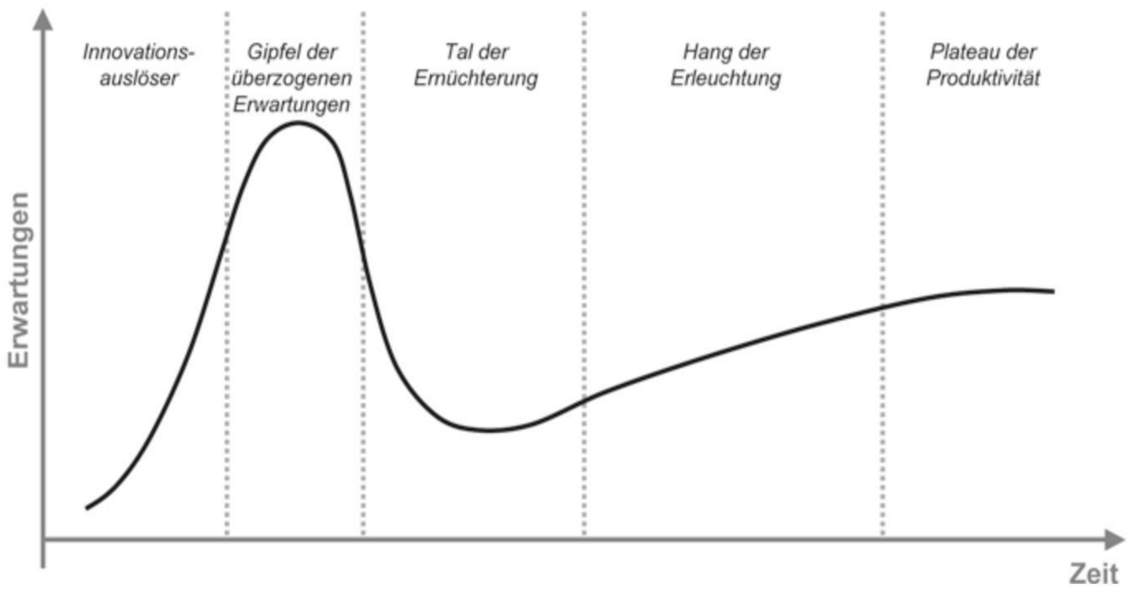

Figure 6: Hype cycle model from Gartner (Schuh & Klappert, 2011, p. 40)

2.3.1.2.2 S-curve concept from McKinsey

The model shown in Figure 7 displays the course of development of the performance of a technology as a function of the cumulative R&D effort. This relation requires, that technologies inevitably reach technical or physical performance limits during their continuous development. According the described concept, four maturity levels of technologies can be identified: 1) Embryonic technology - young technologies, high degree of uncertainty regarding realization possibilities, low priority for companies; 2) Pacemaker technology - first industrial applications, increasing possibility of market break-through; 3) Key technology - established in the market, key technology for individual market segments, increasing risk of being obsolete; 4) Basic technology - performance potential fully utilized, shortly before replacement (Schuh & Klappert, 2011)

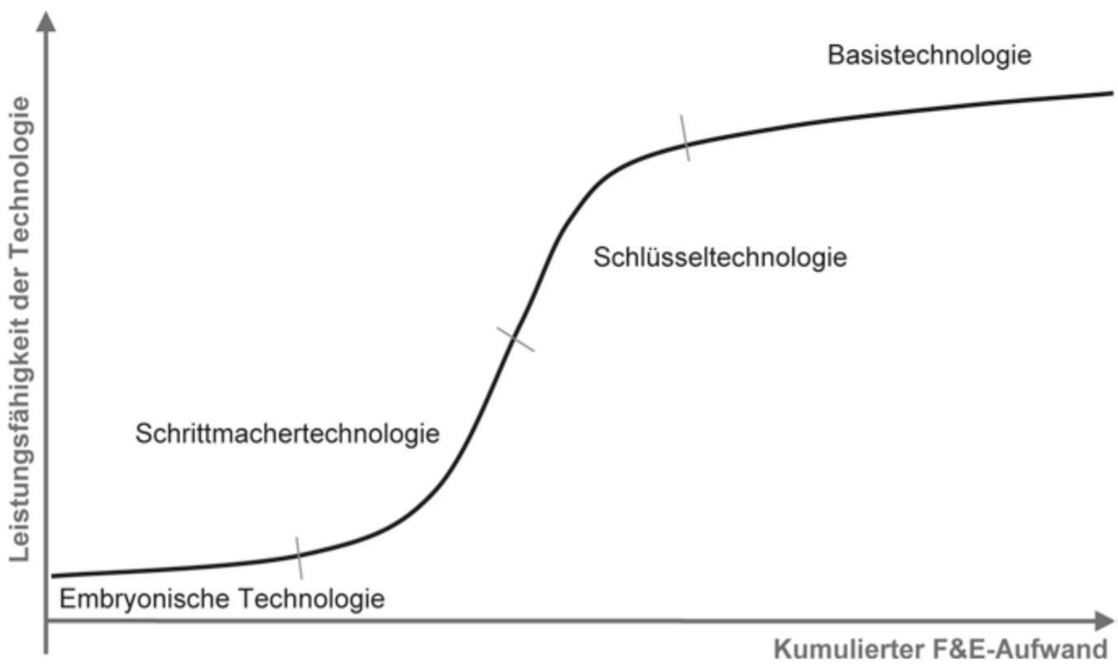

Figure 7: S-curve concept from McKinsey (Schuh & Klappert, 2011, p. 42)

Moreover, the right time of switching from one to another technology is essential for companies. In Figure 8 such comparison of two different technologies is shown. This model can support to select the right moment of switching and showing the remaining potential for further development of the established technology and raise awareness of the potential of new technologies. In any case, the goal behind is to gain the highest possible differentiation contribution in the competitive environment. Nevertheless, it is important to be aware of the potential risks associated with the usage of new technologies. The risk awareness itself is related to the industry the company is dealing in, e.g., companies of the semiconductor industry tend to implement embryonic technologies in their own company and companies in the paper industry tend to set on pacemaker or key technologies. In addition to that known as lock-in and lock-out effects have an impact on the total performance of a technology in a way, that there could be a displacement of the original estimated potential of the technology. This trend is depending on the effort a company is investing in the development of a technology, on possible implementation risks, restrictions, inefficiencies or limiting resources. (Schuh & Klappert, 2011)

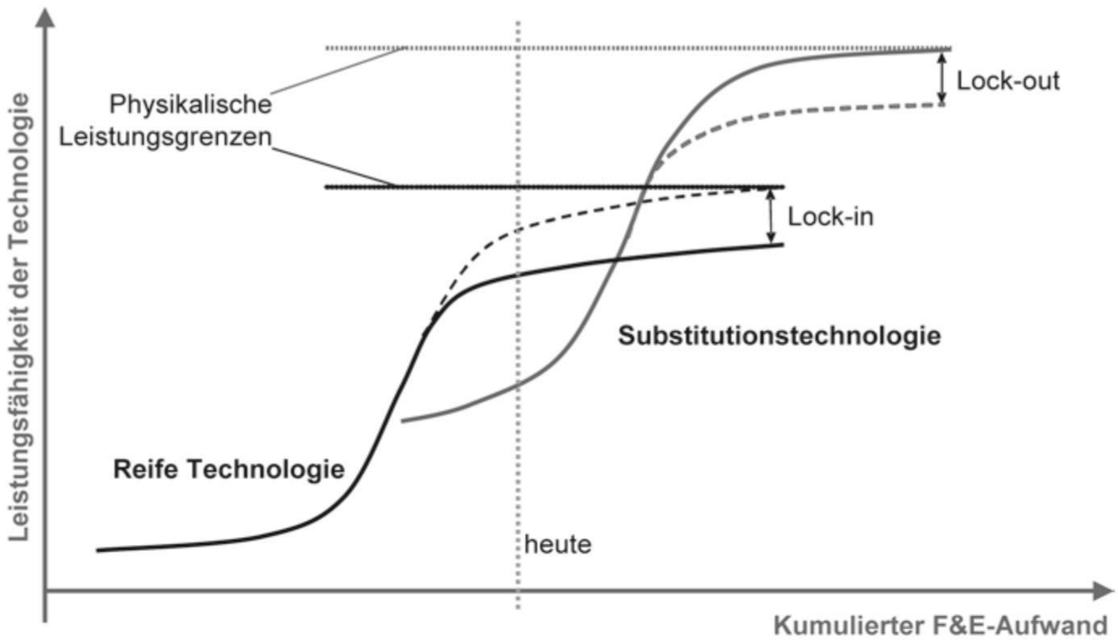

Figure 8: Lock-in & lock-out effect (Schuh & Klappert, 2011, p. 43)

2.3.1.3 Diffusion of technologies

The diffusion of technologies refers to the process by which new innovations, ideas, or technologies spread and become adopted across different individuals, organizations, or communities over time. This process is often characterized by a series of stages or phases, such as awareness, interest, evaluation, trial, adoption, and finally, confirmation or rejection. The diffusion of technologies can be influenced by various factors, including the characteristics of the innovation itself (e.g., complexity, compatibility, relative advantage), the social context in which it is introduced (e.g., social norms, cultural values, communication channels), and the characteristics of the adopters (e.g., innovativeness, risk aversion, social networks). Overall, the diffusion of technologies is a complex and dynamic process that involves interactions between various actors and factors. Understanding these dynamics can be useful for innovators, policymakers, and practitioners who seek to promote the adoption and diffusion of new technologies. (Schuh & Klappert, 2011)

2.3.2 Principles, methods and tools

As a complement to the model of Schuh (2011) which can be seen in Figure 9, also Gregory (1995) has setup a process framework of Technology Management. The content of this model is very similar, although it should be noted that the model of Schuh (2011) is more detailed. For this reason, this work will also use this as the basis for all further considerations. Furthermore, it should be said that the individual elements in the explanations are mutually supplemented, whereby a complete consideration is ensured. In the next chapters each element of Technology Management will be described.

In the subsequent chapter, 2.3.2.1 The regulatory framework according to Schuh and Klappert, the regulatory framework of Technology Management is elucidated, serving as the foundational basis for the entire model analysis in this study. Subsequently, the description of the six phases of Technology Management follows in chapters 2.3.2.2 Early technology detection, 2.3.2.3 Technology planning, 2.3.2.4 Technology development, 2.3.2.5 Technology exploitation, 2.3.2.6 Technology protection, and 2.3.2.7 Technology assessment.

2.3.2.1 The regulatory framework according to Schuh and Klappert

The regulatory framework shows the structured Technology Management and allows a transparent description of the visualized elements. Important is the interaction between the different sections, that is why the key task for the management is to align and coordinate between them and to ensure clear interfaces. (Schuh & Klappert, 2011)

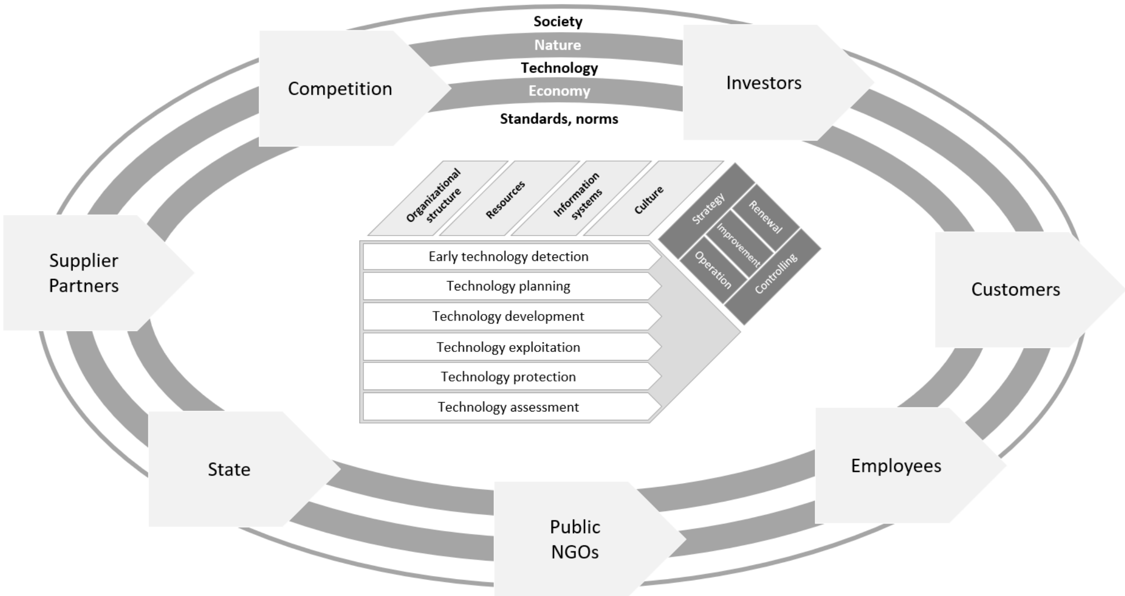

Figure 9: Regulatory framework of Technology Management (Schuh & Klappert, 2011, p. 28)

(translated by the author)

2.3.2.2 Early technology detection

Target of the early technology detection is to detect potential changes in the company's environment in time. It is part of the strategical planning process and ensures a transparent picture for the strategic decision making by linking strategy formulation and technology planning. The focus is to analyze and forecast technological potentials by defining limits of performance of current technologies. The basis for technological decisions is the identification of relevant developments in the environment of a company. (Schuh & Klappert, 2011) The identification of new technologies is aimed at creating awareness of possible technologies relevant for the future, which could bring a decisive advantage to the company. The relevant tasks in this phase are systematic scanning of existing and emerging technologies, progress of internally developed technologies, a deep collaboration with external research organizations and suitable networks according to the company's specific demands. (M.J. Gregory, 1995) (Groenveld, 2007)

2.3.2.3 Technology planning

The central point of technology planning is to define an operational implementation plan, the technology roadmap. It is crucial to take the right decisions within technology planning according to the future orientation and goals. The process defines the technologies and the path of implementation with which the long-term competitiveness is ensured. While the early technology detection describes targets, the focus of the technology planning is to explain the way of execution to reach the defined objectives. Furthermore, the output is to show where the individual technology is coming from and which consequences have to be considered for resource planning. This results in a specific implementation plan for the development and usage of technologies for companies. (Schuh & Klappert, 2011) One specific task in this section is the selection of technologies. Essential to realize is that each decision and orientation is limiting the company's future options. Besides that, a full commitment to the decision is mandatory, because it results in financial and human resource impacts. The planned roadmap is based on an analysis that shows suggested areas the company should focus on, considering technologies the company can easily apply or develop further for their own needs. (M.J. Gregory, 1995) (Daim & Oliver, 2008) (Groenveld, 2007)

2.3.2.4 Technology development

Either internal or external acquisition of technology is possible, internally via proper R&D activities or externally via licensing, joint ventures, or a third party that has an interest in developing such selected technology. All possibilities have to be contemplated in terms of possible strengths and weaknesses. (M.J. Gregory, 1995) The aim of technology development is the execution according to the requirements out of the technology planning process. That means that the development department has to ensure to hold the required timeline in case of a new development or an incremental improvement of an already existing technology in the company. That is why the technology development process is clearly defined to avoid delays. To guarantee a development in time, also external resources can be considered to fulfill the required demand. In addition to that the development team needs to deliver also input for the technology planning process, especially in the pre-phase of defining the technology roadmap. Nevertheless, it is important that strict development processes do not restrict employees creativity too much to stay flexible in case of changes in the companies environment. (Schuh & Klappert, 2011) (Ravasi & Turati, 2005) (Robertson & Gatignon, 1998)

2.3.2.5 Technology exploitation

There are two possibilities to utilize technologies. On the one hand the internal technology exploitation, which concentrates on the usage of unique technological capabilities in products of the company. The aim is to generate a sustainable competitive advantage on a long-term, by applying the technology on several products, sales markets and industries. On the other hand, the external technology exploitation concentrates on offering the technological capabilities to third parties. In this case the profitability of such an investment will be improved, by sharing the knowledge via an organizational cooperation, a license or a sale. (Schuh & Klappert, 2011) Crucial when implementing technologies in products is to consider different possibilities based on market data. Furthermore, when exploiting technologies, it must be taken into account that possible integrations of individual technologies can result in new product functions. Such utilization is desirable in order to amortize high investments more quickly. Finally, it should be said for this process that incremental improvements in the areas of application are important so that these technologies do not expire or become obsolete too quickly. (M.J. Gregory, 1995) (Bianchi et al., 2014) (Lichtenthaler, 2010)

2.3.2.6 Technology protection

The protection of the technology is one of the most important mechanisms in Technology Management. It focuses on avoiding unintentional know-how transfers to third parties. This can be realized by creating ingenious production processes or original technical solutions for a company’s products. Additionally a creative supply chain can support such protection via creating increased entry barriers by extending the vertical value chain, adding extra customized features or obligatory supply agreements with different partners. (Schuh & Klappert, 2011) A possible protection of products and underlying technologies is, for example, to include product features that do not contribute to functionality but are only intended to protect the underlying know-how. Again, it may make sense to adhere to certain standards in order to maintain appropriate market access. The approach always depends on the case under consideration and must therefore be evaluated individually. However, it should be noted that these issues are already taken into account during technology development, technology acquisition and product design. (M.J. Gregory, 1995) (Martínez-Alonso et al., 2023) (Park et al., 2021)

2.3.2.7 Technology assessment

The evaluation of technologies is an element of Technology Management, which impacts all described steps before in this process. To generate an efficient decision making it is crucial to secure appropriate resources for technology assessment. Only then it is possible to have an efficient and effective Technology Management in companies. In other words, each required decision in Technology Management needs an adapted evaluation to that companies are able to choose the right path. By this is meant that all kinds of assessments like for technologies in general, different project goals, or maturity levels of products, require a regular review and if necessary an adoption to the evaluation methods. (Schuh & Klappert, 2011) (Bai et al., 2020) (Garud & Ahlstrom, 1997) (Hellström, 2003)

2.3.3 Summary of Technology Management

Technology Management is a critical discipline that encompasses the planning, development, implementation, and exploitation of technology within organizations. It plays a pivotal role in achieving competitive advantage, enhancing operational efficiency, and driving sustainable growth. Technology Management involves aligning technology decisions with an organization's strategic goals and objectives. This ensures that technology investments contribute to the company's overall success. Organizations must continuously evaluate the relevance and performance of their technology assets. Technology assessment tools and methodologies help in making informed decisions about technology adoption, replacement, or upgrade. In addition, an effective management of intellectual property rights, including patents, trademarks, and copyrights, is crucial for protecting technological innovations and maintaining a competitive edge.

In manufacturing industries, Technology Management involves optimizing production processes, implementing automation and robotics, and adopting Industry 4.0 technologies for improved efficiency and quality. It plays a significant role in healthcare through the adoption of electronic health records, telemedicine, and medical devices. It also encompasses healthcare IT systems and data security. In the IT sector, Technology Management is central to IT strategy, project management, and infrastructure development. It includes decisions about hardware, software, and IT service management. Service organizations utilize Technology Management to enhance customer experiences through digital transformation, online services, and data analytics.

Keeping up with the pace of technological advancements and ensuring that technology investments remain relevant is a constant challenge. Deciding where and how to allocate resources for technology development and maintenance can be complex, requiring careful evaluation of ROI. Overall, it must address ethical considerations related to technology use and navigate regulatory compliance in various industries.

Technology Management will continue to play a crucial role in organizations' digital transformation efforts, with a focus on integrating emerging technologies like AI, IoT, and blockchain. As environmental concerns grow, Technology Management will increasingly involve sustainable technology practices, such as green IT and eco-friendly product design. Organizations will need to manage technology in a global context, considering cultural differences and international regulations.

In conclusion, Technology Management is a dynamic and essential discipline that shapes the future of organizations in various industries. It requires strategic thinking and adaptability to address challenges and opportunities in an ever-evolving technological landscape. Technology Management continues to evolve to meet the changing needs of businesses and society. Researchers and practitioners in the field should remain attuned to the latest developments and trends.

2.4 Lean Technology Management

The combination of Lean Management and Technology Management is certainly a very exciting field of research. In the coming pages an attempt will be made to generate a clear picture, which will be a corresponding challenge due to the complexity and size of the two fields.

There are similarities between manufacturing and R&D, however, upon closer inspection, one notices that the differences are substantial. That means manufacturing is a repetitive, sequential, and bounded activity. It produces physical objects, where risk taking is not a major mechanism for adding value. That is why a manufacturing process is still adding value if you are doing the same thing a million times. In comparison to R&D, where risk taking is a major mechanism. It is an activity, which is non-repetitive, non-sequential and unbounded that produces information. (Donald Reinertsen, 2005)

It is certainly not easy or sensible to transfer or apply lean methods to Technology Management without adjustments, considerations, revisions. The focus should not be on the application itself, but even more on the actual statement of Lean Management and what benefits it can bring to any management discipline. It is much more important to see the guiding principle behind every lean method and to link this with the areas of Technology Management and thus get food for thought in the direction of increasing efficiency and effectiveness. The goal is to make Technology Management leaner, but not to leave out any essential activities. The Lean Technology Management Model is based on Schuh's regulatory framework, which is specifically designed for manufacturing companies. However, this model is also intended for non-manufacturing companies and thus addresses a broad spectrum of applications.

Lean Technology Management is a multidisciplinary approach that combines Lean principles from manufacturing with modern Technology Management practices. It seeks to optimize technology-related processes and innovation while eliminating waste and improving efficiency. This literature review aims to provide an overview of key concepts, principles, and findings related to Lean Technology Management.

Key concepts of Lean Technology Management:

- Lean principles: Lean Technology Management is built upon principles such as minimizing waste, continuous improvement, value stream mapping, and respect for people. These principles are adapted from lean manufacturing and applied to technology and innovation processes.
- Technology adoption: The adoption of new technologies is a critical aspect of Lean Technology Management. Research has shown that organizations need to be agile in adopting and integrating new technologies to remain competitive.
- Innovation: Lean Technology Management emphasizes a culture of innovation. Organizations using this approach foster innovation by encouraging employees to identify and solve problems creatively.

Benefits of Lean Technology Management:

- Efficiency improvement: Lean Technology Management helps organizations streamline their technology-related processes, resulting in improved efficiency and reduced operational costs.
- Waste reduction: By identifying and eliminating waste in technology processes, organizations can allocate resources more effectively and reduce unnecessary expenses.
- Quality enhancement: Lean principles applied to Technology Management can lead to improved product and service quality, reducing defects and customer complaints.
- Faster time-to-market: Lean practices facilitate faster development and deployment of new technologies, allowing organizations to respond quickly to market demands.

Challenges and limitations:

- Cultural resistance: Implementing Lean Technology Management may face resistance from employees who are accustomed to traditional processes. A cultural shift towards embracing change is often necessary.
- Resource allocation: Balancing resource allocation between existing processes and innovation initiatives can be challenging. Organizations must prioritize effectively.
- Measurement and metrics: Defining key performance indicators (KPIs) and metrics that accurately measure the success of Lean Technology Management initiatives can be complex.

Lean Technology Management offers a promising approach to optimizing technology-related processes, fostering innovation, and achieving operational excellence. By adopting lean principles and embracing a culture of continuous improvement, organizations can enhance efficiency, reduce waste, and stay competitive in today's rapidly evolving technological landscape. However, challenges related to cultural change and resource allocation must be carefully addressed to reap the full benefits of Lean Technology Management. Further research and case studies are essential to continue advancing our understanding of this field.

Furthermore, in Chapter 2.4.1 Which meaning of lean is transferable/applicable for Technology Management?, the extent to which specific definitions of lean are relevant to Technology Management is explored. Subsequently, overarching lean principles are categorized in Chapter 2.4.2 Clustering of lean methods to principles, based on existing definitions. In addition, Chapter 2.4.3 Rating of lean methods evaluates lean methods and establishes a corresponding framework, serving as a foundation for further analyses. Following this, Chapter 2.4.4 Adapted Lean Technology Management Model, presents a theoretical LTMM and elucidates the components contained therein.

2.4.1 Which meaning of lean is transferable/applicable for Technology Management?

As discussed in chapter 2.2.1 Definition and understanding there are numerous definitions of "lean." For this reason, there may also be numerous definitions for possible application to Technology Management. An attempt will be made to define it as follows. "Lean" is, after all, merely a collective term which describes the increase in efficiency as well as effectiveness for processes and activities. To ensure and implement this increase, it needs different methods, tools, which were described in Chapter 2.2.2 Lean methods. These methods are to be seen as a toolbox for achieving a leaner state, which will be categorized or linked to defined lean principles. For this reason, the core of the approach is to apply these principles in the best possible way in the right areas. In the following chapters, it will be shown which of these methods can be applied, on the one hand, on the corporate level and, on the other hand, on the level of the Technology Management process as well as other corporate processes, corporate development, and corporate structure.

2.4.2 Clustering of lean methods to principles

According to the literature, the currently defined lean principles can be seen in Figure 10. These principles are specifically focused on the operational area of a company. In order to define a higher level of consideration here, an attempt is made to adopt the meaning of these principles and assign them to higher-level thoughts.

Interrelationship of the principles

High level principles	Lean principles according literature
B, C	Value - Specify value from the customer's point of view
A	Value Stream - identify value stream
C, D	Flow - optimize flow
B, C	Pull - align with customer needs
A, B, C, D	Perfection - strive for perfection

Figure 10: Interrelationship of the principles

The overview of the newly defined lean principles is shown in Figure 11. Those are “standardization & structuring (A)”, “focusing & professionalization (B)”, “continuity & sustainability (C)” and “failure prevention (D)”. Each of these principles lead to different effects, which can be seen in Figure 11.

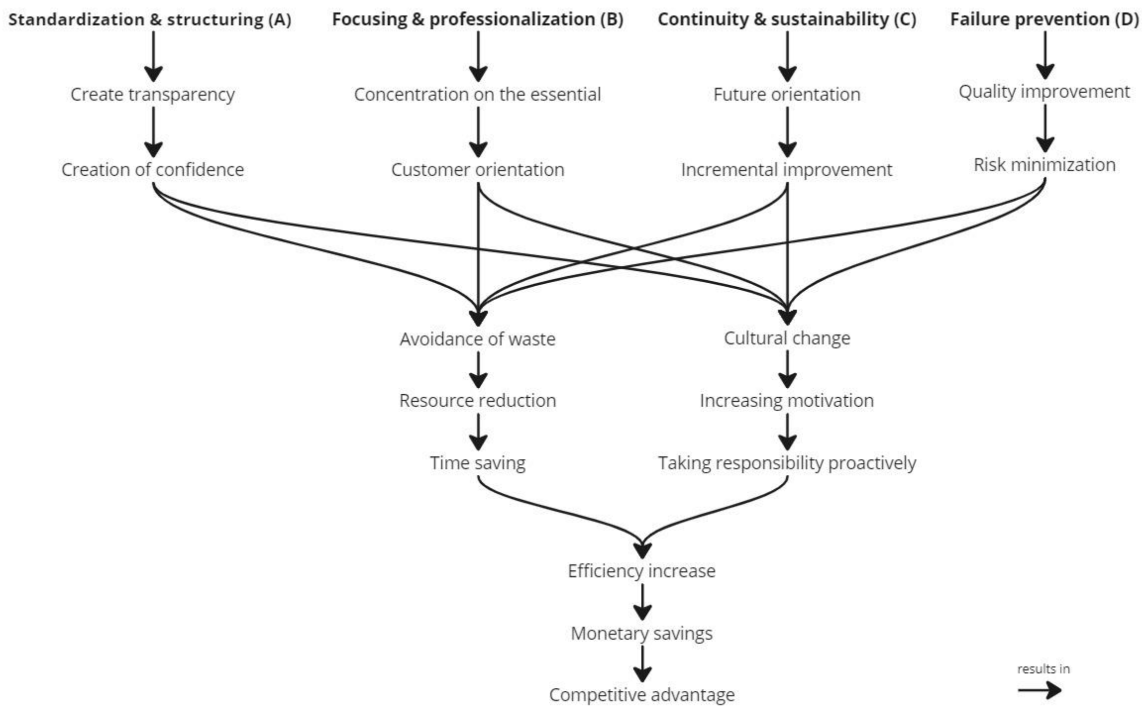

Figure 11: Lean principles and their effects

The various principles have the primary goal of avoiding waste and triggering a cultural change, which results in an increase in efficiency and ultimately brings a monetary benefit, which results in the decisive competitive advantage. In summary, it can be deduced that each method follows at least one of the defined lean principles and thus also its effect, which results when applied. The following is an explanation of why there are four principles. By selecting these four principles, a comprehensive foundation for the successful organization and execution of projects or activities is established. They complement each other and contribute to ensuring long-term success and competitiveness:

Standardization and structuring (A):

- Justification for selection: Standardization and structuring are fundamental principles across various domains, particularly in science and management. By implementing standards and structures, processes can be rationalized, efficiency can be enhanced, and errors can be reduced.
- Exclusion of alternatives: While other principles such as flexibility and adaptability are important, standardization and structuring are necessary to ensure consistent quality and performance.
- Consistency and completeness: Standardization and structuring form the foundation for many other processes and principles. They are closely interrelated and enable the effective implementation of other principles like professionalization and sustainability.

Focusing and professionalization (B):

- Justification for selection: Focusing and professionalization are crucial for enhancing the quality of work and outcomes. By concentrating on specific goals and developing expertise, organizations can improve their effectiveness.
- Exclusion of alternatives: While flexibility and versatility are important aspects, focusing on specific goals and professionalizing the workforce enables a more targeted and efficient approach to work.
- Consistency and completeness: Focusing and professionalization complement each other by setting clear objectives and enhancing the skills of employees, contributing to the achievement of long-term strategic goals.

Continuity and sustainability (C):

- Justification for selection: Continuity and sustainability are essential for the long-term success of an organization. By ensuring stability and considering ecological and social aspects, organizations can create long-term value.
- Exclusion of alternatives: Although short-term goals and rapid changes are important, continuity and sustainability are necessary to ensure long-term stability and growth.
- Consistency and completeness: Continuity and sustainability are closely intertwined, contributing to organizations taking long-term responsibility and considering their impacts on the environment, economy, and society.

Failure prevention (D):

- Justification for selection: Preventing failures is crucial for ensuring the quality of products and services and maintaining customer trust. By identifying and rectifying errors, organizations can enhance their efficiency and reduce costs.
- Exclusion of alternatives: Although flexibility and adaptability are important, preventing failures is crucial to ensuring the quality and reliability of products and services.
- Consistency and completeness: Failure prevention is closely linked with other principles such as standardization and structuring. Clear processes and quality controls enable errors to be detected and rectified early on.

2.4.3 Rating of lean methods

As already discussed in Chapter 2.2.2 Lean methods, the lean methods listed here are not a complete listing of all existing Lean Management methods, processes or tools. The methods listed are based on systematic literature research and are noted according to their frequency of occurrence.

The next step is to evaluate the individual methods in terms of their applicability to the Technology Management process. This evaluation has been performed based on the assessment and understanding of the topic. Table 6 shows this evaluation. Each process step of the Technology Management process has been evaluated with regard to the applicability of the respective lean method from 1 bad, 2 neutral and 3 good. Furthermore, "other corporate processes", "corporate structure" and "corporate development" have been evaluated on the basis of the regulatory framework of Schuh. The content of the individual process steps is described in Chapter 2.4.4 Adapted Lean Technology Management Model. The evaluation of the individual process steps results as a sum and can be seen in the column "level of relevance" in Table 6. Furthermore, the lean principles are clustered into four groups as discussed in Chapter 2.4.2 Clustering of lean methods to principles. This cluster is intended to serve as an overarching guide to the application of possible methods. The reference of the individual principles for applicability to the Technology Management process can also be seen in Figure 13.

If we now sort the results from Table 6 in ascending order of level of relevance, these principles show up at the top, which have the best applicability. On the one hand, the overall rate of relevance is shown, which includes all business processes, and on the other hand, the rate of relevance is shown purely to the Technology Management process. Both give almost the same result in total, it only changes the order of the top ten methods, but none is added or removed. In summary, this means that in a possible application, the focus should be on these ten methods, shown in Table 7, those are classified as well applicable and thus taken as a suggestion for the future user of the Lean Technology Management Model.

Standardization & structuring (A)
Focusing & professionalization (B)
Continuity & sustainability (C)
Failure prevention (D)

Assigned principle	Level of relevance (total)	Level of relevance (TM)	Lean method	Technology management process						Corporate business		
				Early technology detection	Technology planning	Technology development	Technology exploitation	Technology protection	Technology assessment	Other corporate processes	Corporate structure	Corporate development
A, B, C	22	13	Kaizen/CIP	2	**3**	2	**3**	2	1	3	3	3
A, B	22	13	VC	2	2	1	2	**3**	**3**	3	3	3
C, D	19	12	FMEA	1	1	**3**	**3**	1	**3**	3	2	2
B	19	12	Five whys	2	2	2	2	1	**3**	3	2	2
A, C	20	11	7 wastes	1	**3**	2	**3**	1	1	3	3	3
B	20	11	Gemba	**3**	2	2	2	1	1	3	3	3
A, B	19	11	5S	2	2	1	**3**	1	2	3	3	2
B	18	11	Pareto	1	2	**3**	**3**	1	1	3	2	2
D	17	10	Poka Yoke	1	2	1	**3**	2	1	3	2	2
B, C	17	10	TOC	2	1	2	2	1	2	3	2	2
A, C	16	9	Kanban	1	**3**	1	2	1	1	3	2	2
A, B, C	16	9	JIT	1	**3**	1	2	1	1	3	2	2
D	15	9	QFD	1	2	2	2	1	1	3	1	2
D	14	8	TQM	1	1	2	2	1	1	3	1	2
A, C	14	8	Jidoka	1	2	1	2	1	1	3	2	1
B	14	8	ABC	2	1	1	2	1	1	3	2	1
C, D	13	8	TPM	1	2	2	1	1	1	3	1	1
A, B	13	8	VSM	1	2	1	2	1	1	3	1	1
A	13	8	OEE	1	2	1	2	1	1	3	1	1
C, D	12	7	SMED	1	1	2	1	1	1	3	1	1
C, D	12	7	Six Sigma	1	2	1	1	1	1	3	1	1

Rating: 1… bad; 2… neutral; 3… good

Table 6: Rating and clustering of lean methods

Lean principle	Lean method
A, B, C	Kaizen/CIP
A, B	VC
C, D	FMEA
B	Five whys
A, C	7 wastes
B	Gemba
A, B	5S
B	Pareto
D	Poka Yoke
B, C	TOC

Table 7: Top 10 methods for Technology Management

2.4.4 Adapted Lean Technology Management Model

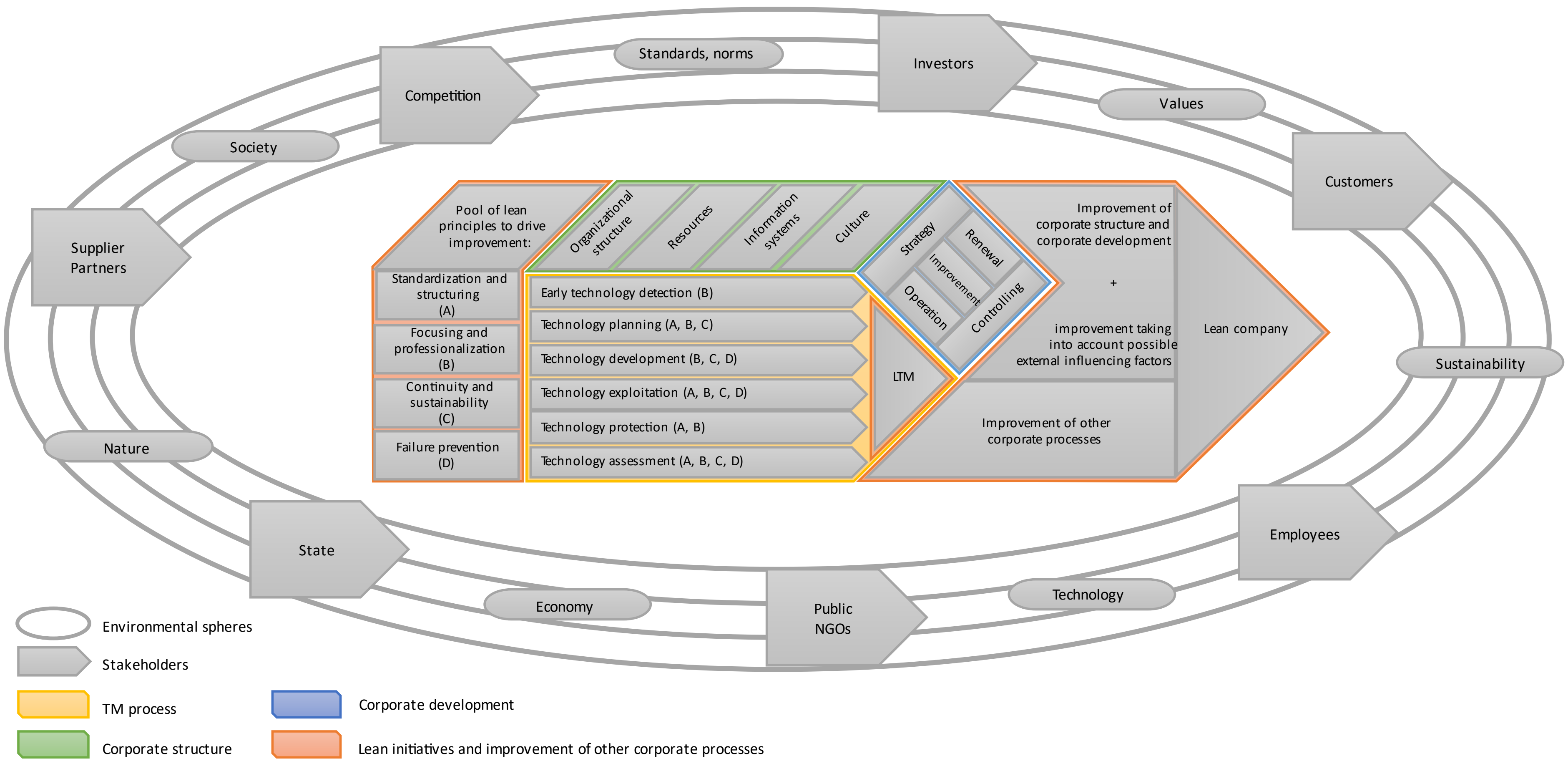

Figure 12: Adapted Lean Technology Management Model

Furthermore, in the subsequent chapters, the contents of the adapted LTMM are delineated. In Chapter 2.4.4.1 Environmental spheres and stakeholders, the environmental contexts and stakeholders are addressed. Additionally, Chapter 2.4.4.2 Technology Management process, describes the process of Technology Management in conjunction with Lean Management, elucidating potential applications. Following this, Chapter 2.4.4.3 Corporate structure, explains the corporate structure in the context of the adapted LTMM. The final segment is covered in Chapter 2.4.4.4 Corporate development. The conclusion is presented in Chapter 2.4.4.5 Lean initiatives and other corporate processes, which provides an outlook on improving further business processes.

2.4.4.1 Environmental spheres and stakeholders

Companies exist to create value for stakeholders. This benefit is different from the perspective of the various stakeholder groups. They can be categorized into internal and external stakeholders. Internal stakeholders include employees, managers, and shareholders, while external stakeholders consist of customers, suppliers, government agencies, communities, and non-governmental organizations (NGOs). In the representation of the model in Figure 12, the stakeholder groups are arranged in a circle. Furthermore, the environmental spheres in which companies act are shown here. These influencing factors have different effects on a company and its processes.

In terms of sustainability a company's operations and activities affect the three dimensions (Dyllick & Hockerts, 2002):

- Environmental sustainability: This sphere focuses on the company's impact on the natural environment. It includes factors such as the company's carbon emissions, energy and resource consumption, waste generation and management, pollution levels, and conservation efforts. Environmental stakeholders can include environmental activists, local communities, regulatory bodies, and environmental NGOs.
- Social sustainability: The social sphere pertains to the company's impact on society and human well-being. It includes factors such as labor practices,

employee welfare, human rights, community development, and social responsibility initiatives. Social stakeholders may include employees, local communities, customers, consumer advocacy groups, and human rights organizations.

- Economic sustainability: The economic sphere refers to the financial performance and economic impact of the company. It includes factors such as profitability, economic growth, job creation, taxes, and economic contributions to local or national economies. Economic stakeholders can include shareholders, investors, employees, suppliers, and government bodies.

These spheres are interconnected, and interdependent, and sustainable business practices aim to balance the interests of all stakeholders while minimizing negative impacts on the environment. Responsible companies strive to consider the needs and expectations of their stakeholders across all spheres to achieve long-term success. The individual environmental spheres and stakeholder groups will not be discussed further in this paper. However, it is worth mentioning that Lean Management always focuses on the customer. Thus, the customer is automatically at the center of attention and thus represents the central stakeholder group.

2.4.4.2 Technology Management process

Here, an attempt is made to show, by way of example, to what extent lean principles can be interpreted in the individual sections of Technology Management and thus find a possible application. It is important that the actual sense and benefit of the individual method is applied. For this reason, there are countless possibilities of interpretation, the following are possible examples, which are intended to provide inspiration for their own application. In addition, the defined lean principles should serve as the basis for the respective Technology Management process step.

	Standardization & structuring (A); Focusing & professionalization (B) Continuity & sustainability (C); Failure prevention (D)									
	Kaizen/ CIP	VC	FMEA	Five whys	7 wastes	Gemba	5S	Pareto	Poka Yoke	TOC
Early technology detection (B)	2	2	1	2	1	3	2	1	1	2
Technology planning (A, B, C)	3	2	1	2	3	2	2	2	2	1
Technology development (B, C, D)	2	1	3	2	2	2	1	3	1	2
Technology exploitation (A, B, C, D)	3	2	3	2	3	2	3	3	3	2
Technology protection (A, B)	2	3	1	1	1	1	1	1	2	1
Technology assessment (A, B, C, D)	1	3	3	3	1	1	2	1	1	2

Lean Technology Management

Figure 13: Detail on Lean Technology Management

- **Early technology detection**

  Lean methods from category (B) are recommended for application in this process section. The principle of focusing and professionalization (B) describes the effect of reducing all activities to the essentials and focusing on the customer. In relation to the process section of early technology detection, this means, for example, that the majority of activities are always focused on the essentials during technology scanning, followed by technology monitoring and finally technology scouting. This keeps the focus clear and the efficiency high, but it is still important to keep an eye on the environment at all times so as not to miss any trends. Another important task is to concentrate on the essentials when determining the need for information, only then can work be done in a targeted and resource-saving manner. Subsequently, it is also necessary to select one's sources of information in such a way that the essential need is optimally fulfilled. Technological search fields, in which a differentiation from the competition is possible from time view, as well as an exclusivity of the data brings along, is to be classified as decisive competitive advantage. As already mentioned, if an information source may be as good as it is, but has no relation to the essential, it is important to discard it and not to merge it any further, at least not to keep it in focus, but to consider it as a possible environment extension at the edge. An example of principle (B) is the Gemba method in connection with early technology identification. On the basis of Figure 13, it can be seen that the method Gemba is rated most highly for early technology detection. The idea is to be close to the action. The closer one is to the source of information, the better risks e.g., for possible developmental delays can be assessed and incorporated into one's decision-making. It is about understanding existing challenges and assessing possible consequences, this inevitably leads to a reduction of wrong decisions and enables an increase in efficiency in the use of resources. Also rated high is the method of Kaizen/CIP and VC, it should be noted that in this specific case, access to knowledge is to be standardized. The rapidly increasing amount of available and thus potentially relevant knowledge can be accessed through a wide variety of channels. Here, a possible competitive advantage can be developed by screening an orderly and easily manageable area through standardized processes. It has no added value to look at everything, this is not even possible, it is important that there is no overload of information. To complete the lean idea, other methods from the principle (B) can be applied here.

- **Technology planning**

  Lean methods from the categories (A), (B) and (C) are recommended for application in this process section. These principles require the application of different methods, see Figure 11, which result in an increase in transparency, concentration on the essentials and future orientation as well as customer orientation. With reference to technology planning, this means that the result of technology planning, the technology roadmap, takes all these principles into account by applying the defined methods. This results in benefits in technology selection, identification of capabilities, the right timing in terms of when is the best time to implement, as well as in the actual implementation of individual projects. These advantages result in making the right decisions based on a clear focus, which is based on transparency and customer orientation. On the subject of customer orientation, it should be said that what were once enthusiasm features evolve into performance features until they finally mutate into basic requirements. It is important to note here that there is no need even for enthusiasm features if potential customers are only prepared to pay for basic features. For this reason, in terms of sustainability, customer focus is crucial and should have a significant influence on decisions. To ensure that the implementation of the technology plan is also successful, technology controlling is an essential component for success. Here, the PDCA cycle from the Kaizen/CIP method can be used to be able to react to deviations early, agilely and efficiently. Furthermore, this method can be used as the overarching basis for technology planning. According to Figure 13, it can be seen that for technology planning, the lean methods of Kaizen/CIP and 7 wastes are rated highest. This is intended to anchor the idea of an iterative process in order to be able to adapt to constantly changing framework conditions in an agile manner. It is therefore clear from the outset, that there will be changes, which are to be incorporated according to standardized procedures. Possible changes of various kinds, be it a change in technology, the period of use of a technology, the source of the technology, changes in the product portfolio (synchronization between product and technology planning), the economic influence of technologies, etc., must be evaluated by means of standardized processes and embedded in the technology planning. Furthermore, attention should be paid to possible wastes. Here the method of the 7 wastes can be used. In terms of technology planning, for example, this would be to push for timely decision-making; translated, this would result in low waiting times. Another possible optimization is to plan exclusively with technologies at a defined development depth that are actually implemented. Translated, this would mean not tolerating buffers or overproduction as well as over-perfection and thus not wasting resources.

- **Technology development**

  Lean methods from the categories (B), (C) and (D) are recommended for application in this process section. These principles result in concentration on the essentials, risk minimization, quality enhancement and future orientation as well as customer orientation. In terms of technology development, this means ensuring that selected technologies can be used efficiently and, in a customer-oriented manner. These technologies are used both in products and in their manufacturing processes. It should be noted that in technology development the underlying ideas are rather abstract. This means that there is only a slight product reference since the so-called pre-development has the goal of developing a deep understanding of the field under consideration. Here, the principles for risk minimization contribute to success and can provide appropriate input based on the focus for decision making. This means, for example, that it can make sense to conduct FMEAs at early stages. This approach also applies to product development, which is the next step in the process. It is important to understand that technology development has a different focus than product development. In technology development, the focus is on customer benefit and the degree of disruption as well as the degree of innovation, whereas in product development, the focus moves toward the cost, time and quality of the products. Nevertheless, different principles can contribute to improvements and efficiency gains in both cases. Figure 13 shows that for technology development, the method FMEA and Pareto are ranked highest. Kaiezn/CIP in the sense of Lean Management provides the basis for an orderly development process. Although this is not rated highest here, it is needed in order to document accordingly, to have clear processes and, for example, to be able to develop employees accordingly with regard to their competencies. In order to reduce risks and errors, it is possible to evaluate and classify products and processes proportionally by means of FMEAs and to derive appropriate measures. This method is more or less a standard for the evaluation of products in the development process (Design FMEA) as well as in the production (Process FMEA). Here it is now necessary to apply this method to the development process of technologies, in which the process itself is evaluated. Another potential is offered by a somewhat more radical approach, which, however, also entails a corresponding risk. According to Pareto (80/20) to concentrate purposefully on the so-called 20 percent with the development of technologies and to begin already prematurely with the development of products. In combination with a FMEA a synergy effect can be formed here, which makes the risks tangible and thus calculable. These approaches can reduce corresponding development times and thus create competitive advantages with a positive outcome.

- **Technology exploitation**

  Lean methods from categories (A), (B), (C) and (D) are recommended for application in this process section. The effects of the principles from categories (A), (B), (C) and (D) include an increase in transparency, focus, future orientation and risk minimization. Consequently, the overall result is an increase in efficiency, which results in cost savings. The use of technologies is a long-term matter, which must be organized sustainably. Sustainable in the sense of building up focused technology competencies that are intended to benefit several product generations. This can only be achieved if transparency is practiced with regard to the know-how in the company, as well as working in a future-oriented and customer-focused manner. Furthermore, synergy potentials are to be exploited by using technologies for several products. Here, too, it is important to think across departments and as a whole in order to make this possible. Lean principles from all categories form the basis for strengthening the effects described. According to Figure 13, the lean methods of Kaizen/CIP, 7 wastes, FMEA, 5S, Pareto, and Poka Yoke are the highest ranked for technology exploitation. After all, technology exploitation is about getting the most out of the entire technology portfolio. For this to be successful, the entire technological knowledge available must be clearly organized and presented in a structured manner. The Kaizen/CIP and 5S methods can be used here. Kaizen/CIP in the sense of standardization and 5S in the sense of a clear structure and understanding of technologies in-house. In this context, it also means that obsolete technologies that are no longer up to date are adopted in a timely manner. On the other hand, the technologies in focus must be kept up to date and used within the framework defined in the planning. Furthermore, in the sense of maximizing benefits, it is also important to concentrate on the so-called 20 percent, according to Pareto, in order to act as efficiently as possible. Poka Yoke can, for example, provide input in the form of clear communication of known errors in the case of external technology utilization, i.e., the transfer of technologies to third parties for use. This is particularly the case when these third parties operate in the company's own supply chain. This brings enormous sympathy points and strengthens the customer/supplier relationship, which can bring competitive advantages in difficult times. Translated, this would mean that errors are prevented before they can occur.

- **Technology protection**

  Lean methods from categories (A) and (B) are recommended for application in this process section. Transparency and trust in combination with concentration on the customer with a simultaneous focus on the essential activities. These effects result from the application of methods from categories (A) and (B). In terms of technology protection, this means that smart protection mechanisms should serve as appropriate barriers to entry. These must be developed before a technology is copied. In the spirit of Poka Yoke, mistakes must be avoided before they can even occur. It is important to know one's market in terms of transparency. In this way, competitor products or even imitators can be recognized early and, if possible, appropriate countermeasures can be initiated, and thus almost no market share is lost. In the fight for market share, the quality of products is essential; here, too, lean methods can enable a decisive competitive edge. As can be seen in Figure 13, the lean method of VC is ranked highest for technology protection. Extensive investments in research and development, the aim of which is to secure the company's future profits, must be protected accordingly in order to secure a sustainable competitive advantage. The guiding principle of VC can be applied here, in which all activities relating to the protection of know-how are processed according to certain rules. Consistency and transparency are important keywords in this case from the field of VC, which can be transferred one-to-one to the process of technology protection. In terms of standardization, this means that all activities must be completed, complete and traceable. Only then is it possible to protect knowledge accordingly. If this area is mishandled, entire technologies can turn out to be an economic failure from the innovator's point of view. Further food for thought from the area of standardization for technology protection is, for example, to integrate all technology protection activities in advance as a standard in the development process. However, it is important to ensure that the development itself does not become too complex so as not to promote unnecessary activities that extend development times. It is also important here that a company-wide standard of information sources is defined and the focus is centralized. Who stores where, what, in what format, form, authorizations, etc., this question is essential in this context for example.

- **Technology assessment**

  Lean principles from categories (A), (B), (C) and (D) are recommended for application in this process section. All four principles ultimately aim to increase efficiency. This is achieved through the application of the respective lean methods, which enhance the effects to achieve the decisive competitive advantage. When considering technology assessment, it is important to promote transparency and consider all criteria as a basis for decision-making. As a cross-cutting function, technology assessment has an impact on upstream process steps. Early technology detection, technology planning, technology development and technology exploitation are areas that rely on the input of assessment. In early technology detection, for example, it is a matter of being able to interpret the high level of uncertainty correctly. By concentrating on the essentials, decision-making can be facilitated by recognizing even weak signals that are in focus. Furthermore, due to a prevailing high level of complexity, it is important to create clear structures that provide a good overview and thus facilitate judgment. In the area of technology planning, it is advisable to secure decisions accordingly, since at this point in time they are characterized by a high scope.

This is characterized by a high use of resources as well as a highly competitive relevance. Here, lean methods increase transparency in order to be able to present an impact assessment well. This applies equally to technology development and technology utilization; furthermore, customer benefits must always be included with appropriate priority. Figure 13 shows that for the technology assessment, the lean methods VC, Five Whys and FMEA are highly rated. Technology assessment is the determination of the advantages and disadvantages of different alternatives from different perspectives, which takes place by means of measuring or estimating parameters of the assessment objects. In order to increase the efficiency of decision making, the principle of VC enables a transparent presentation of different KPIs, so that the important parameters are always accessible to the decision makers. To ensure that this presentation is and remains meaningful, the principle of standardization also lays the foundation for success here. It must be clear which data is required for which key figures and how these are calculated. This required data must then be organized in a standardized manner and continuously checked for accuracy. Only then can reliable trends be derived, and decisions made. For risk minimization, the principle of FMEA can be used here in parallel as an evaluation tool. The goal is to be able to better assess all risks and to mitigate their potential dangers or to consciously accept them with countermeasures.

2.4.4.3 Corporate structure

The following areas of the corporate structure are only briefly described here in an overview. Recommendations are made in some cases and potential is highlighted, but the description is not to be regarded as complete and may therefore contain gaps. It should be noted that this area can also serve as a basis for the application of various lean methods. For this section, principles from the categories (A), (B) and (C) are recommended.

- **Organizational structure**

  The organizational structure of a company is designed to achieve defined goals as effectively as possible. In order to achieve an increase in efficiency, various lean methods can have a supporting effect. From the point of view of Lean Management, care must be taken not to avoid or reduce unnecessary and non-value-adding activities and to focus centrally on the customer. The most diverse structures in companies, from functional, divisional, team-based to matrix organization, etc., must be in harmony with the different company processes. Only then processes with clear responsibilities can be efficiently installed, and only then does it make sense to apply lean methods for optimization.

- **Resources**

  Resources in a company are understood to be the various tangible and intangible assets used to conduct business activities and achieve corporate goals. From the point of view of Lean Management, it is in turn about the efficient, purely value-adding use of resources. Reducing this to value-creating activities is a challenge that companies must meet. It is important that resources of all kinds are taken into account, such as human, financial, physical, intellectual, time and many more. Furthermore, when using resources, it is always important to question the customer benefit as well as to act in a future-oriented and sustainable manner.

- **Information systems**

  Information systems are the integrated set of components, technologies, and processes that collect, process, store, and distribute information within an organization to support decision making, coordination, control, and operational activities. Information systems play a critical role in modern enterprises by enabling efficient data management, improving communication, and providing valuable input for strategic decision-making. The heart of a company is the so-called ERP system (enterprise resource planning system). This typically includes modules for finance and accounting, human resources, inventory management, production planning, procurement, forecasting and more. ERP systems enable better coordination, efficiency and transparency across different departments and locations within the company.

- **Culture**
  Culture in a company refers to the shared values, beliefs, norms, behaviors and practices that shape the work environment and influence how employees interact with each other, approach their work and align with the company's goals. Corporate culture plays a critical role in shaping the organization's identity, attracting, and retaining employees, improving performance, and fostering innovation. Building and maintaining a positive corporate culture requires conscious effort by leaders and consistent reinforcement of desired behaviors and values throughout the organization. By fostering a strong corporate culture, companies can cultivate a productive and engaging work environment, attract top talent, and achieve long-term success. Lean management places greater emphasis on customer focus. Corporate culture influences the organization's approach to customer service and satisfaction. A customer-centric culture emphasizes understanding and meeting customer needs, providing excellent service, and building long-term relationships. It instills a sense of ownership and accountability for delivering value to customers.

2.4.4.4 Corporate development

The following areas of the corporate development are only briefly described here in an overview. Recommendations are made in some cases and potential is highlighted, but the description is not to be regarded as complete and may therefore contain gaps. It should be noted that this area can also serve as a basis for the application of various lean methods. For this section, principles from the categories (A), (B) and (C) are recommended.

- **Strategy**
  In general, it can be distinguished between business and corporate strategy. A business strategy focuses on an individual market and a corporate strategy

covers a set of businesses together. However, company strategies vary depending on the industry, market, and specific goals of the organization. Here's a broad overview of what a typical company strategy might entail (Schuh & Klappert, 2011):

- Vision and mission: The company should have a clear vision of what it aims to achieve in the long term and a mission statement that outlines its purpose and core values.
- Market analysis: Understanding the market in which the company operates is crucial. This involves analyzing industry trends, competitors, customer needs, and potential opportunities.
- SWOT analysis: Assessing the company's strengths, weaknesses, opportunities, and threats helps in identifying areas of improvement and where the company can leverage its strengths.
- Goal setting: Based on the market analysis and SWOT analysis, the company should set specific, measurable, achievable, relevant, and time-bound (SMART) goals.
- Target audience: Defining the target audience and understanding their preferences and pain points is essential for effective marketing and product development.
- Competitive advantage: Identify the unique selling propositions (USPs) that differentiate the company's products or services from competitors and emphasize those advantages.
- Product/service strategy: Outline the company's offerings and how they align with customer needs and market trends. Determine whether the focus will be on innovation, cost leadership, differentiation, etc.
- Marketing and sales strategy: Define how the company will promote its products/services and reach its target audience. This includes branding, advertising, sales channels, and pricing.
- Financial strategy: Develop a financial plan that includes budgeting, revenue projections, cost management, and investment decisions.

- Human resources strategy: Attract, develop, and retain a skilled workforce that aligns with the company's goals and culture.
- Risk management: Identify potential risks (financial, operational, legal, force majeure, etc.) and create plans to mitigate them.
- Technology strategy: Assess how technology can be utilized to improve efficiency, enhance products, or create new business opportunities.
- Sustainability and corporate social responsibility (CSR): Define the company's commitment to sustainable practices and social responsibility.

A successful strategy is not a static document but a living framework that should evolve and adapt to the dynamic business environment. It requires regular reviews, updates, and flexibility to remain effective. (Bowman & Helfat, 2001)

- **Renewal, Improvement, Operation**

  Renewal refers to the process of revitalizing or reinvigorating the company to remain relevant and competitive in the ever-changing business landscape. It involves identifying areas that require change and making strategic adjustments to adapt to new market conditions and challenges. Some key aspects of renewal include innovation, technology, market research, business model evolution, agility to change etc.

  Improvement involves making incremental changes and optimizations to various aspects of the company to enhance efficiency, productivity, and overall performance. It focuses on refining existing processes and practices rather than introducing radical changes. Examples of possible areas to improve are quality control, process optimization, cost management, employee development, customer experience etc.

  Operations refer to the day-to-day activities and functions required to run the company efficiently. Effective operation management ensures that resources are utilized optimally to achieve organizational goals. Key components of operational management include supply chain management, inventory management, logistics, financial management, human resources management, technology and IT support, health and safety, etc.

Successful companies continuously focus on renewal, improvement, and efficient operation to maintain a competitive edge and adapt to the changing business landscape. Regular assessment and adjustment of strategies in these areas are essential for sustained success and growth.

- **Controlling**

  Controlling is an important function in business management that involves monitoring, measuring, and regulating various processes and activities to ensure that the organization's goals are achieved efficiently and effectively. Controlling provides feedback, identifies deviations from planned results, and takes corrective action to keep the company on track. Controlling is essential to ensure that the organization stays on track toward its goals, identifies opportunities for improvement, and maintains the efficiency and effectiveness of its operations. It is a dynamic process that requires flexibility and adaptability as the business environment evolves. For this reason, there are different perspectives in controlling, namely goal orientation, future orientation, market orientation, customer orientation and bottleneck orientation. All orientations must be taken into account accordingly and evaluated and presented in a balanced manner. Controlling should provide the company with information regarding the achievement of goals, weak points as well as risks and opportunities. Controlling depicts the company's operations in Figures. (Brecht, 2012)

2.4.4.5 Lean initiatives and other corporate processes

In addition to Technology Management, there are many other important disciplines in a company that should be given at least as much attention. The other business processes will not be discussed in detail here, but recommendations for the application of possible lean principles will be given, the overview can be seen in Table 8. These other key business processes are, for example, Innovation Management, R&D Management, Factory Planning, Production and Logistics Management, Quality Management, Purchasing Management, Industrial Service Management, Sales Management, Marketing Management, and Digitalization and Information Management etc.

Corporate process	Category of lean principle
Innovation Management	A, B, C
R&D Management	B, C, D
Factory Planning	B, C
Production and Logistics Management	A, B, C, D
Quality Management	C, D
Purchasing Management	A, B
Industrial Service Management	B, C, D
Sales Management	B, C
Marketing Management	B, C
Digitalization and Information Management	A, B, C, D

Table 8: Recommended lean principles for corporate processes

Part III

Empirical Research

3 Empirical Research

3.1 Aims and Structure of the Chapter

Management field research is conducted through systematic studies based on the collection of original data in real organizations. Ensuring the quality of field research hinges on a crucial criterion: methodological suitability. Methodological suitability is defined as the internal consistency among the various elements of a field research project. These elements encompass the research question, addressing theoretically and practically significant inquiries, narrowing down the scope to meaningful proportions, and formulating answerable questions. It also includes the existing literature, identifying relevant constructs and highlighting unanswered questions or areas with low consensus, the research design, and, finally, the contribution to the literature. The research questions and their underlying considerations were already discussed in Chapter 1 Research Intent, while the theoretical background was summarized in Chapter 2 Theoretical Background and Concept of the LTM-Model. Chapter 3 now elucidates all empirically collected data and the process by which they were obtained. Specifically, in Chapter 3.2 Research Design and Methods, the fundamental process of the entire research strategy is explained. Subsequently, in Chapter 3.3 Content-structuring Qualitative Content Analysis, a detailed methodology for conducting qualitative content analysis is presented. Finally, Chapter 3.4 Empirical Findings, describes all empirically collected data.

3.2 Research Design and Methods

Primary data collection is employed to substantiate the findings of the literature review. Furthermore, a qualitative survey method is chosen, specifically via expert interviews. These interviews were semi-structured and relied on a questionnaire that incorporated questions derived from both the research questions and theoretical findings. The questionnaire was created on the basis of the descriptions provided by (Gläser & Laudel, 2009). In addition, the intricate aspects of conducting these interviews and processing the collected data was performed. In terms of the evaluation method the guidance of (Kuckartz & Rädiker, 2022) is followed, exploring a seven steps approach. The content-structuring qualitative content analysis is used, which proved to be the most suitable approach for this particular context. In Chapter 3.2.1 From research questions to guideline questions, the derivation of interview questions and their interconnections is explained. Chapter 3.2.2 Interview partners, introduces the interviewed companies and the positions of the interviewees. Finally, in Chapter 3.2.3 Conducting and processing of interviews, the process of conducting interviews is explained, detailing how the interviews were carried out and processed.

3.2.1 From research questions to guideline questions

An often-encountered mistake in expert interviews is overlooking the crucial step of translating research questions into interview questions (Gläser and Laudel, 2010). The significance of this process is often underestimated despite being essential for obtaining valuable answers. In light of this, an advanced interview guide was developed, serving as a comprehensive checklist throughout the interviews. The formulation of the interview guide's questions stemmed directly from the research questions. An approach rooted in building from the ground up was employed, considering the research questions and identifying the necessary answers from interviewees to address them accurately. The questions were crafted with clarity and precision to elicit essential information. Each question underwent scrutiny to assess its potential contribution to the findings and relevance of each research question. If a question was deemed insightful, it earned a place in the interview guide. Additionally, tables were employed as a tool for posing questions, offering an additional avenue for obtaining revealing insights. Finally, the following structure was established:

Introduction - Simple introductory questions about the interviewee's tasks in the company. Further warm-up questions on the main topics.

Main part - is divided into two sections. The first part relates to Lean Management and Technology Management, as well as possible combinations of the two subject areas and a survey of the level of knowledge. The second part focuses on the designed model, which is the center of attention here.

Conclusion - final questions on what has been discussed.

Table 9 provides a summary of the content delivered by each interview question and its corresponding research question. The complete interview guideline utilized during the interviews is available in the appendix.

Content and related research question	***Associated interview questions***
Introduction questions (warm-up questions) (RQ1, RQ1.1)	Questions 1, 2
Potential and risks of applying LM on TM (RQ1, RQ1.1, RQ1.2, RQ1.3)	Questions 3, 4
Review of the level of knowledge about lean methods	Questions 5, 6
Lean principles for TM (RQ1.3)	Question 7
Lean methods for TM (RQ1.3)	Question 8
Completeness of the LTMM (RQ2.1)	Question 9
Usability of the LTMM (RQ2, RQ2.2, RQ2.3)	Questions 10, 11

Table 9: Relation of research questions to the interview questions

3.2.2 Interview partners

To be able to select suitable interviewees, it is crucial to first identify individuals who possess the necessary information for the desired reconstruction. Acquiring all the relevant information typically entails interviewing multiple actors who, due to their specific positions in the process to be reconstructed, have different sets of information. Rarely it will occur in reconstructive investigations that one interviewee has all the pertinent information. Even in such cases, it is advisable not to limit oneself to conducting just one interview. (Gläser & Laudel, 2009)

The selection of companies and interviewees in this study was driven by several considerations. On the one hand, attention was given to covering a broad range of industries in which the companies operate. However, the primary focus is on technology companies that derive their value through the development and/or production of products, processes, or services, aiming to enhance competitiveness. To gain significant insights, it is crucial to engage with the relevant decision-makers who possess specialized expertise. Individuals in relevant positions were therefore selected to provide insights into the subject. On the other hand, there must also be a certain openness to sometimes sensitive topics. This means that there must be a willingness and time on the part of the interview partners for such interviews. Only then can genuine added value be created. It is important to emphasize that all companies insist on strict confidentiality and anonymity.

An overview of the companies in terms of industry, turnover and number of employees, as well as the position of the interview partners, can be seen in Table 10. In the fourth quarter of 2023, interviews were conducted with a total of 29 companies.

Company	*Sales in million €*	*Number of employees*	*Role of interviewee(s)*	*Industry*	*General business*
Company A	101 - 1000	1001 – 10k	Head of Global Technology and Innovation Management	Mechatronic manufacturing	Automation and assembly
Company B	10 - 100	< 250	Chief Technical Officer	Electronic manufacturing	PCBA and other assembly
Company C	101 - 1000	< 250	Chief Executive Officer & Process Development Manager	Food manufacturing	Animal processing
Company D	101 - 1000	250 - 1000	Chief Technical Officer & Head of Sensor-based Sorting	Mechanical and plant engineering	Development and construction of plants in the field of processing and environmental technology
Company E	10 - 100	250 - 1000	Lead Engineer Product Development	Automotive	Development of testing technology in the automotive industry
Company F	101 - 1000	1001 – 10k	Chief Operations Officer	Automotive	Development and production of engine and drive components
Company G	> 1000	> 10k	OPEX and Lean Manager	Wood processing	Production of wood-based materials
Company H	10 - 100	250 - 1000	Chief Executive Officer	Electronics and mechatronics	Development and production of mechatronic drive systems
Company I	101 - 1000	250 - 1000	Leader E-Commerce as a Service	E-Commerce	Development and fulfillment in E-Commerce
Company J	> 1000	> 10k	R&D head for business line MSP	Electronics and mechatronics	Development and production of semiconductors and other electronics
Company K	< 10	< 250	Head of R&D	Electronics and mechatronics	Development and production of heating foils
Company L	> 1000	> 10k	Manager Technics	Paper and pulp	Paper and pulp production
Company M	101 - 1000	1001 – 10k	Director Global Quality	Wood processing	Production of winter sports articles, hard goods
Company N	> 1000	> 10k	Manufacturing Strategy, Technology and Digital Operations	Automotive	Development and production of vehicle components

Company O	101 - 1000	250 - 1000	General Manager	Mechanical and plant engineering	Development and production of machinery
Company P	> 1000	> 10k	Head of strategic production management EMT	Vehicle construction	Development and production of vehicle components
Company Q	> 1000	1001 – 10k	Chief Operations Officer	Metal and wood processing	Manufacture of capital goods and business equipment
Company R	< 10	< 250	Chief Executive Officer	Metal processing	Production of height adjustable furniture
Company S	> 1000	1001 – 10k	Vice President Product Management	Intralogistics	Development and construction of intralogistics systems
Company T	101 - 1000	1001 – 10k	Customer Strategy Manager & Authorized Signatory	Consulting	Implementation and support of ERP systems
Company U	10 - 100	250 - 1000	Head of Technology & Digitalization	Electronics and mechatronics	Development and production of tools
Company V	10 - 100	250 - 1000	Head of Operations	Electronic manufacturing	PCBA and other assembly
Company W	> 1000	> 10k	Director Corp. Technology & Innovation Mgmt. and Operational Excellence Manager	Electronics and mechatronics	Development and production of printed circuit boards
Company X	10 - 100	< 250	Head of Technology Management & Plant Design	Chemical plant engineering	Development and construction of chemical plants
Company Y	> 1000	> 10k	Manager OPEX	Steel production	Development and production of steel
Company Z	101 - 1000	250 - 1000	Chief Executive Officer	Mining	Development and production of metal powder
Company AA	10 - 100	250 - 1000	Chief Executive Officer	Electronics and mechatronics	Development and manufacture of lighting equipment
Company AB	< 10	< 250	Chief Executive Officer	E-Commerce	Development and fulfillment of adjustable furniture
Company AC	> 1000	> 10k	Head of Operational Excellence for BU's and Head of Lean for Business Units	Electronics and mechatronics	Development and production of tools

Table 10: List of companies interviewed

3.2.3 Conducting and processing of interviews

The interviews were conducted partially in person on-site at the respective companies and partially online via Microsoft Teams. All conversations were audio-recorded and subsequently transcribed with the assistance of artificial intelligence. The use of artificial intelligence was limited to the transcription domain, indicating that the interviews were transcribed using artificial intelligence, while all other steps were performed without artificial intelligence assistance. All relevant units of meaning, coded through the multi-stage coding process, were also appropriately corrected. Interview partners consented to the recording and processing of data, provided that absolute discretion and anonymization were ensured. Furthermore, the recording commenced only after introducing and explaining the conversation flow, resulting in an average recording duration of approximately one hour. Detailed implementation data for the interviews can be found in Table 11.

Company	***Interview date***	***Interview Duration hh:mm:ss***	***Recorded***	***Fully transcribed***
Company A	20231011	00:53:38	yes	yes
Company B	20231012	01:06:13	yes	yes
Company C	20231013	00:56:53	yes	yes
Company D	20231017	00:51:18	yes	yes
Company E	20231018	01:11:00	yes	yes
Company F	20231020	00:51:51	yes	yes
Company G	20231027	01:24:52	yes	yes
Company H	20231028	00:52:07	yes	yes
Company I	20231031	00:55:44	yes	yes
Company J	20231102	00:35:36	yes	yes
Company K	20231105	01:01:56	yes	yes
Company L	20231106	00:55:30	yes	yes
Company M	20231104	00:50:03	yes	yes
Company N	20231108	01:01:09	yes	yes
Company O	20231109	01:02:43	yes	yes
Company P	20231110	00:43:39	yes	yes
Company Q	20231113	00:46:05	yes	yes
Company R	20231115	01:04:44	yes	yes

Company S	20231116	00:50:10	yes	yes
Company T	20231117	00:58:24	yes	yes
Company U	20231119	00:36:35	yes	yes
Company V	20231120	00:52:56	yes	yes
Company W	20231122	00:51:16	yes	yes
Company X	20231201	00:43:01	yes	yes
Company Y	20231204	01:03:00	yes	yes
Company Z	20231205	00:58:28	yes	yes
Company AA	20231212	00:38:08	yes	yes
Company AB	20231213	00:37:46	yes	yes
Company AC	20231219	01:05:37	yes	yes

Table 11: Detailed information of each interview

3.3 Content-structuring Qualitative Content Analysis

Qualitative content analyses, proven effective in numerous research projects, have been described in methodological literature in various forms and are acknowledged for their structuring of content. Regarding the development of categories employed in content structuring content analysis, a wide spectrum is evident, ranging from fully inductive category formation based on the material to largely deductive category development. However, the two poles of category formation – fully inductive and fully deductive – are seldom encountered in their purest form in research projects. In most cases, a multi-stage process of category formation and coding is applied. (Kuckartz & Rädiker, 2022)

A similar multi-stage procedure was also employed in this study. Figure 14 illustrates the seven-phase process of content-structuring analysis, starting from the research questions. For the analysis of the transcribed data, MAXQDA software (version 24.0.0) was employed. The activities in the individual phases are described as follows:

Phase 1 - The content-structuring qualitative analysis commences with a careful and attentive reading of the text, marking passages deemed particularly significant. Comments and annotations are written in the margins, while any noteworthy observations during the reading, along with spontaneously arising analysis ideas, are documented in the form of memos. (Kuckartz & Rädiker, 2022) In this study, brief keyword summaries were handwritten after each interview, serving as a preliminary guide for the subsequent analysis.

Phase 2 - In qualitative content analysis with structural organization, a systematic arrangement of data is achieved through the utilization of main categories and subcategories. Themes and subthemes often serve as analysis categories. Regardless of whether the main categories and subcategories are developed directly from the material or derived deductively from a theoretical framework, research questions, or the study's guide, it is advisable to conduct a pilot run with a portion of the data. This allows for the examination of the main categories and subcategories, as well as their definitions, for their specific applicability to the empirical material. The amount of material used for category testing depends on the overall volume and complexity of the category system. (Kuckartz & Rädiker, 2022) In this study, the main categories were developed based on the literature review, research questions, and the resulting questionnaire. The overview can be seen below in Table 12.

Main categories	***Associated interview questions***
Organization of Lean Management	Question 1, 5, 6
Organization of Technology Management	Question 2
Application of lean principles or methods in Technology Management	Question 3, 4, 7
Lean Technology Management Model	Question 8, 9, 10, 11

Table 12: Main categories and associated interview questions

Phase 3 - The initial coding process is conveniently structured to go through each text sequentially, i.e., line by line, from the beginning to the end. Text segments are then assigned to main categories by deciding which category is addressed in the respective section. Non-meaningful text passages or sections irrelevant to the research question remain uncoded. For example, in thematic coding, it should be considered that a text segment may address multiple themes, necessitating the assignment of several categories to individual units of meaning. (Kuckartz & Rädiker, 2022) The four main categories initially used for coding are shown in Table 12. Due to varying conversation trajectories, it emerged that different segments were assigned multiple categories.

Phase 4 - In a content-structuring content analysis, there is typically a refinement of initially more general categories after the first coding process. This applies, at least, to the categories that hold central significance for the study. (Kuckartz & Rädiker, 2022) In this study, all main categories were refined through the inductive formation of subcategories. This involved systematically reviewing some text passages associated with each main category. Subsequently, these subcategories were organized, and corresponding category definitions were formulated to facilitate further coding of the material.

Phase 5 - Once subcategories have been formed, a labor-intensive phase follows—namely, a second coding process where the differentiated categories are assigned to the text passages previously coded with the main category. This represents a systematic step in the analysis, requiring a thorough review of the already coded material. It is essential to ensure that a sufficient amount of material was used for the differentiation of the main categories in Phase 4. If subcategories were formed based on too little material, it is often observed that clarifications and expansions of the subcategories are necessary. (Kuckartz & Rädiker, 2022) The sample for the inductive creation of subcategories was chosen to be extensive, resulting in a significant amount of work. However, this approach ensured that every significant piece of material could be assigned without exception, thereby guaranteeing a high quality of analysis. In total, 1221 segments were assigned. The complete codebook, code cloud, and graphical representation of code frequencies across all documents, including the number of assignments and category definitions, can be found in the appendix.

Phase 6 and 7 - During this phase, both simple and complex analyses take place, and the preparation for presenting the results occurs. In the context of content-structuring qualitative content analysis, the focus naturally revolves around themes and subthemes in the evaluation process. The category-based analysis along the main categories serves as the starting point in most studies. However, subsequent analysis forms vary depending on the study. While one study may emphasize cross-case, category-oriented analysis, another may be dominated by a case-specific approach, and in a third, both approaches may be treated equally. Visualizations play a special role in this context, serving as an independent form of analysis on one hand, and on the other hand, being used in various other analysis forms, such as in the form of tabular case summaries. (Kuckartz & Rädiker, 2022) The results of this step are presented in Chapter 3.4 Empirical Findings.

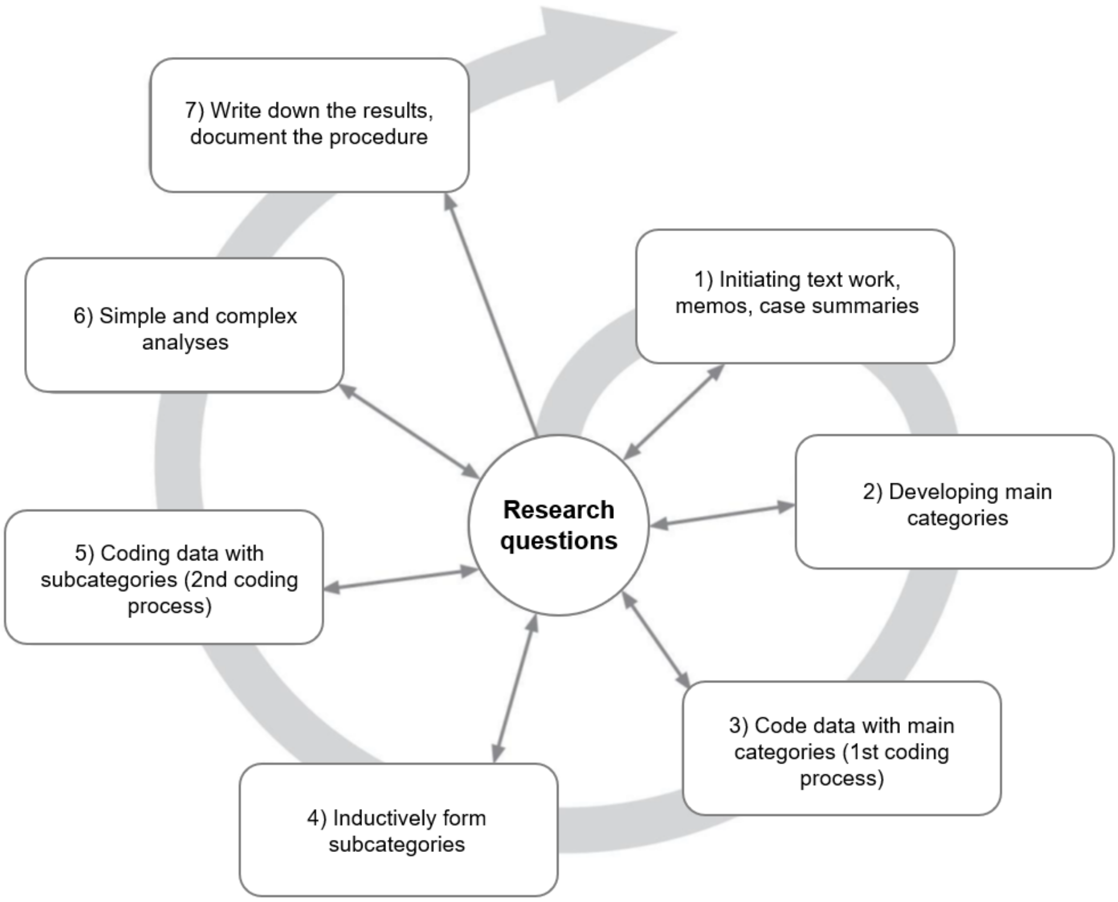

Figure 14: Procedure of a content-structuring qualitative content analysis in 7 phases (Kuckartz & Rädiker, 2022, p. 132) (translated by the author)

3.4 Empirical Findings

In this section, a detailed presentation of all empirically obtained data is provided. This information stems from expert interviews conducted with individual company representatives, as outlined in Table 10. The initial segments, 3.4.1 Organization of Lean Management and 3.4.2 Organization of Technology Management, offer an overview of the organizational structure and the level of knowledge within the companies regarding the two key topics. Subsequently, Chapter 3.4.3 Lean thinking in Technology Management delves into the integration of Lean Management with Technology Management. Here, we explore the opportunities, risks, and potentials associated with applying lean principles in Technology Management. Finally, Chapter 3.5 Design of a Lean Technology Management Model outlines all challenges, advantages, and other improvement suggestions concerning the Lean Technology Management Model, as depicted in Figure 12 based on the literature.

3.4.1 Organization of Lean Management

In this chapter all gathered information regarding the topic of Lean Management in companies is presented. The aim is to understand the extent to which companies utilize the subject area and to portray their perspectives. Additionally, results concerning the level of awareness and application of specific lean methods are presented here. The comprehensive summary is depicted in Table 13. Followed by Chapter 3.4.1.1 Naming of Lean Management, which explores how Lean Management is referred to in companies. Next is Chapter 3.4.1.2 Understanding and effects of Lean Management, where the understanding of Lean Management in companies is discussed. The conclusion is presented in Chapter 3.4.1.3 Knowledge of Lean Management, demonstrating the existing knowledge of Lean Management within companies.

Organization of Lean Management	Companies
Organization across the board – The majority of the company's departments are actively involved in their respective lean programs. Some companies, such as Company F, follow a top-down approach. Within the goal-setting framework, there are mandatory participation requirements and clear performance goals measured through KPIs. Company Q also establishes global goals through Lean Management. In parallel, there are dedicated lean teams responsible for the implementation of various methods. These lean teams act either as internal consultants for departments or employees from different departments can be part of the lean teams, as is the case with Companies L, W, and Y. These teams provide comprehensive methodological expertise and oversee lean activities. In addition, these teams or external experts offer training at all levels. Companies strive to reflect on their actions regularly and derive corresponding improvement measures. For example, Company M defines products on a quarterly basis in categories such as losers and winners. Based on this, analyses are initiated, and measures are derived and implemented through small projects.	F, L, M, N, Q, S, W, Y, Z, AC
Partially organized according to need – In these companies, there is no global lean program; instead, activities are implemented, and methods are chosen individually based on specific needs. Company A articulates this as: "*This decentralized structure results in a lack of comparability.*" While these companies recognize potentials, their implementation is not always straightforward. Furthermore, workshops with external partners are occasionally planned and conducted. For companies with multiple locations, comparability suffers, as highlighted by Companies A and G, unless uniform standards are established. Moreover, these companies primarily focus on implementing Lean Management in the production	A, B, D, G, H, I, J, K, O, T, U, V, X, AA

area, with other departments mentioned only to a limited extent. Company H describes this approach: "*As mentioned, our focus is primarily on areas close to production. While I am aware that there are approaches to implement lean methodologies in areas such as development, we haven't systematically introduced them beyond our core focus on production-related areas.*" In a project-based context, other organizational areas are integrated into Lean Management. An example is Company J, which incorporates improvement potentials from production into development without standardization. Additionally, Lean Management is not treated as a separate entity, as described in the first category; rather, it is integrated as a subordinate part in various departments.	
Not organized at all – Lean Management is partially known within the company but lacks organized implementation. Some methods are used intermittently, but there is no consistent focus on their execution. This is exemplified by Company T. Additionally it is mentioned that methods are unconsciously applied but are not explicitly recognized as such. There are initiatives to drive improvements, but they do not necessarily originate from the context of Lean Management. Furthermore, the focus varies depending on the age of the company. For instance, in the case of a scale-up like Company AB, the primary goal is often to achieve the break-even point.	C, E, P, R, T, AB

Table 13: Organization of Lean Management

3.4.1.1 Naming of Lean Management

During individual discussions, it quickly became apparent that Lean Management evokes various emotions among the participants, both positive and negative. This is influenced by their experiences and stories from colleagues, as Lean Management is not always interpreted in the same way as described in the literature. Companies like G, W, N, and AC describe Lean Management as focusing on increasing process efficiency, but some argue that it should also enhance effectiveness. For this reason, the term OPEX (operational excellence) is utilized, as it encompasses both aspects. Another synonym, described by Company L, is the "Performance Engine," motivated by negative associations with lean initiatives that led to workforce reductions. Company Y echoes these concerns, stating, "*the biggest risk is the word lean.*" Furthermore, Company T notes, "*In these medium-sized enterprises, like ours, Lean Management practices are present but are not explicitly labeled as such.*" In summary, it can be said that Lean Management is a familiar term to many, but the interpretations of what it entails vary. What is crucial, however, is that it elicits both positive and negative emotions. Additionally, different companies use diverse labels to refer to the concept of Lean Management.

3.4.1.2 Understanding and effects of Lean Management

It has been observed that the interviewed companies have different interpretations of Lean Management. While there is some overlap, it does not fully encompass the entire potential of Lean Management. Companies C, F, G, H, M, and Z emphasize that the mindset of all employees is crucial for successful Lean Management. This involves a clear focus on the customer through goal setting and the most efficient way of achieving it, with a certain flexibility allowed due to changing influencing factors. Company H succinctly states: "*I believe the focus in Lean Management is aiming to increase efficiency and align more with customer needs.*" Lean Management supports concentrating on the essentials and placing the customer at the center, with cost considerations playing a central role. On a more pragmatic note, companies E, L, N, O, and AC approach the topic differently. Their focus is explicitly on the application of individual methods with the goal of minimizing or avoiding waste, using various metrics as targets. The operational area takes precedence here. On the other hand, Company T employs Lean Management intuitively through experienced employees. This means that explicit methods are not applied, but due to the long-standing experience of employees, parts of methods are intuitively implemented, with conscious efforts towards improvement. Lean Management is seen here as a supporter of optimizations.

The effects resulting from Lean Management are described by the companies as changes and improvements brought about through various courses, training, or similar measures. For example, Company B emphasizes: "*Today, we are actively applying the knowledge gained from our past Kaizen workshops, including the use of FMEA.*" Company F has been actively using various dashboards since its first encounter with Lean Management to track metrics in a standardized way. The positive impacts on operational areas, such as production, supply chain, or logistics, are particularly highlighted by companies D, G, L, O, T, and W. Company G succinctly states: "*With Lean Management, you can't go wrong.*"

3.4.1.3 Knowledge of Lean Management

In order to assess the awareness of methods and establish a benchmark for their frequency of application in companies, the conducted expert interviews specifically inquired about this. The following Figure 15 present the results. It indicates which methods are known to the companies, and shows which of these methods are actually implemented in each respective company. Interestingly, while some companies rely solely on internal expertise, others recognize the value of seeking external assistance, whether it be through consulting firms or specialized training programs. Approximately ten of the surveyed companies explicitly seek external support for Lean Management, driven both by situational needs and through regular training for both existing and new employees.

Companies B, G, O, V, and Z have implemented tailored training programs for different levels within their organizations, specifically focusing on Lean Management. Company S emphasizes that even interns undergo a two-day seminar upon their entry: "*Even our trainees receive two-day seminars on this topic.*" A notable example is Company L, which actively employs 74 different lean methods.

In summary, it can be said that the following eight methods are among the top ten methods in both rankings, which can be seen in Figure 15, once sorted by application of the methods and once sorted by awareness of the methods: Kaizen/CIP, 5S, Visual Control System via KPIs, Pareto, FMEA, Kanban, Five Whys and ABC. All of these methods are explained in Table 4.

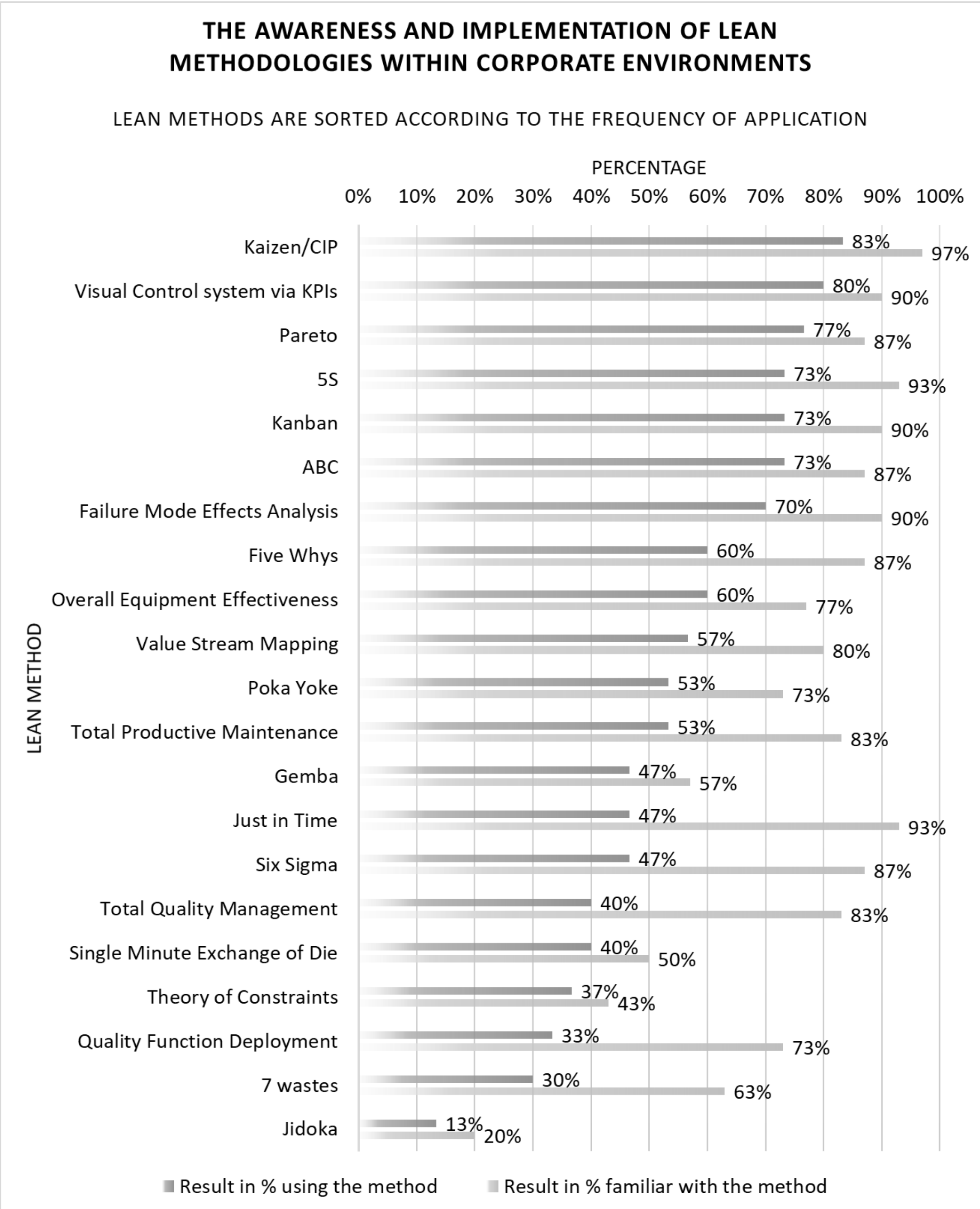

Figure 15: The awareness and implementation of lean methodologies within corporate environments

3.4.2 Organization of Technology Management

In this chapter, all collected information on the topic of Technology Management in companies is presented. The aim is to understand the extent to which companies utilize this thematic focus and to portray their perspectives. Additionally, results regarding improvement potentials mentioned by the companies are summarized. The comprehensive summary is depicted in Table 14, followed by Chapter 3.4.2.1 Knowledge of Technology Management, where the companies' knowledge in this area is vividly described. Additionally, Chapter 3.4.2.2 Improving Technology Management outlines improvement suggestions as well as barriers to enhancing Technology Management as reported by the interviewed companies.

Organization of Technology Management	**Companies**
Organization across the board – The listed companies represent the majority of the process steps in Technology Management. These steps are embedded in various departments and processes, which are accordingly implemented within the companies. It is worth noting that while the companies may not necessarily categorize Technology Management into precisely these six subareas, they do cover all these aspects within their respective structures. Company G emphasizes the relevance of Technology Management in a systematic approach within the organization. The focus is on clear definition of activities, setting goals, identifying strengths, and aligning with corporate objectives. Company AC highlights that the process includes applied research, exploration of new technologies, and the implementation of insights into product development. Company U places importance on global Technology Management for production facilities and stresses the balance between development, innovation, product management, and basic technologies. Some companies have established their own technology and innovation management teams, addressing strategic aspects, corporate alignment, and technology portfolio definition. Company Y underscores the	A, D, G, H, J, L, N, S, U, W, Y, Z, AC

importance of technological leadership for competitiveness, innovation, and achieving strategic corporate goals. Additionally, centers of competences are set up to remain technologically advanced. A structured development approach, encompassing technology selection, strategic resource allocation, and continuous improvement of development processes, is employed in many companies. An example of this is the Advanced Product Quality Planning (APQP) practiced by Company H. In conclusion, the companies unanimously agree that commitment to the latest available technology and early detection of technologies through market feedback and internal product management are crucial.	
Partially organized according to need – The companies mentioned here engage in Technology Management but have not fully established it. Company E states that they currently do not implement centralized Technology Management because their approach is heavily customer-oriented, with product development being influenced more by project requirements than proactive market research. Additionally, Company AA mentions that their technology foresight is created through an annual overview called the “*Technology Radar*”. In Company P, there is a separate department for emerging technologies, focusing on research, development, and series production of innovative topics. Furthermore, depending on the need, as seen in Company M, Technology Management varies between brands, with each unit managing its own technology specialists. The organization initiated a strategy process defining the direction for the next years and identifying key themes. Company B follows the approach of assigning a dedicated technologist or expert for each technology. In Company X, there is a technology manager who establishes schedules, including the duration for the use of specific technologies. In summary, it can be said that partial aspects of Technology Management are implemented and actively practiced.	B, E, F, M, P, Q, R, T, X, AA

Not organized at all – The mentioned companies do not have a defined process or subprocess for Technology Management. Nevertheless, it's worth noting that parts of Technology Management are implemented and actively practiced. Company O states that it lacks a specific process for Technology Management. Some elements are integrated into the development process but are not explicitly outlined. Product management plays a crucial role in identifying customer needs and early technology detection. Company K has established an innovation circle, a small group within the company tasked with generating new ideas from internal resources. These ideas are evaluated based on their potential value, and a budget is allocated for the most promising ones. In Company I, the approach is highly flexible. Technology Management is distributed across many departments, allowing teams to generally work autonomously. Conversely, in Company AB, the responsibility lies solely with the CEO: "*Innovation has always been my passion. I believe it has been a crucial aspect of my company's history so far, allowing me to stand out through groundbreaking ideas.*" In Company C, there are no documented specific steps for how individual processes unfold. There is no established sequence or defined process for it. Company V mentions that their Technology Management is limited to attending a trade fair, the so-called "*Productronica*", to see the latest developments in production technology. However, primary actions are driven by customer requirements.	C, I, K, O, V, AB

Table 14: Organization of Technology Management

3.4.2.1 Knowledge of Technology Management

The term Technology Management is often unclear, and it has been observed that companies alone may not fully grasp the comprehensive nature of what it entails. Therefore, it was crucial to clarify in advance what is meant by this term. It should be noted here that almost none of the interviewed companies categorize Technology Management into the six areas defined by Schuh and Klappert. This implies that there is no uniform definition of this essential topic within the companies. Nevertheless, as previously mentioned in Table 14, many areas are indeed covered in substance. Consequently, various examples are described illustrating what companies do in the field of Technology Management. For instance, Company Z describes the topic as follows: "*I believe that Technology Management must be closely linked to personnel recruitment, as this creates immense expertise within the organization. This includes having our own technology and research departments and granting them the necessary autonomy. We ensure that our employees in these areas also maintain external contacts, whether with colleagues or customers, and that there are enough customer projects available.*" Furthermore, Company N explains that it has an idea box for employees to submit their ideas. Additionally, each center of competence is provided with a trend analysis on an annual basis. The task of the center is then to create a gap analysis based on the strategy and thus actively initiate projects to fill the gaps. Company Y mentions collaborating closely with universities in terms of Technology Management to avoid having to develop everything independently. On the other hand, Company O states that collaboration with universities is not typically done, and reliance is placed solely on representatives in the industry. For Company W, Technology Management primarily encompasses the development process and close collaboration with the operational area, which employs lean methods. It emphasizes the importance of early integration of these methods into the development process. The goal is to optimize processes strategically using these methods and deliver high-quality products. Furthermore, Company C mentions from its own experience that knowledge is strongly tied to individuals, leading to knowledge gaps in case of absence. Thus, knowledge distribution within a company is a crucial and often overlooked issue. In summary, it can be said that the expertise in Technology Management varies significantly among companies. On one hand, some companies are well-organized in this area and theoretically cover all focal points. On the other hand, some companies selectively implement specific content.

3.4.2.2 Improving of Technology Management

Potentials for improving Technology Management – Various companies identify diverse potentials for optimization in Technology Management. For instance, companies G and Q emphasize that significant optimization potential exists in both the digitalization of processes and the interactions between different business processes. In this context, it is crucial, especially for companies with multiple locations, to establish appropriate networking to effectively tap into all potentials. An illustrative example highlights that the application of technology in different areas can lead to the emergence of new business opportunities. Furthermore, Company Z actively aims to integrate the operational domain into the development processes. This results in a cohesive unit that systematically optimizes products and processes, thus becoming more efficient in the long term. The key is not only to train the individuals involved but also to adapt the processes accordingly, ensuring that there are no deviations from the standard.

Barriers in Technology Management against improvement – The interviewed companies highlight various barriers to optimization activities in Technology Management. These resistance factors can be categorized as industry-specific, process-related, investment-related, and social-culturally related barriers. Companies emphasize challenges in the practical implementation of management methods, particularly in dealing with corporate culture and the complexity of hierarchical structures. The discussion extends to the risks associated with introducing Lean Management and other methodologies, emphasizing the importance of understanding individual perspectives and handling organizational change cautiously. Interview participants from companies K and P acknowledge difficulties in implementing changes in established companies, where resistance to new methods may occur. This requires a delicate balance between navigating existing practices and promoting innovation. The acceptance of such changes in a large company is highlighted as a significant point. Companies G and AA stress that the meaningfulness of optimizing Technology Management depends on the industry. A certain standard and industry inertia may render activities in this direction not crucial for sustainable business success. Company A describes limited opportunities for optimization due to non-adjustable process parameters, particularly in production-related applications of technologies. Company AC argues that the Technology Management process alone cannot be optimized by lean methods, as many interfaces would suffer. The discussion extends to the challenge of dealing with systems that have grown over decades in the company, particularly concerning changes, especially in digital processes that are challenging to reverse. In summary, companies A, N, G, and AC point out specific challenges in lean implementation in certain processes. They emphasize the need for careful considerations in Technology Management and outline the complexities and risks associated with organizational systems and digitalization. Finally, companies C and G stress that high investments are sometimes necessary, which alone can lead to the abandonment of optimization attempts.

3.4.3 Lean thinking in Technology Management

In the dynamic landscape of Technology Management, the pursuit of optimal efficiency and continuous improvement is commendable. The present contents delve into the possibilities of integrating Lean Management into the context of Technology Management, deciphering nuanced challenges, and gaining valuable insights from various corporate perspectives. In this investigation, we navigate through the intricate interplay of lean thinking, customer focus, and process optimization, seeking to unravel the key factors for success in the realm of Technology Management. Chapter 3.4.3.1 Greatest potentials with lean thinking in Technology Management, begins by outlining the significant potentials for lean thinking in Technology Management, specifically focusing on the individual phases of Technology Management. This is followed by Chapter 3.4.3.2 Risks in application of lean methods, principles in Technology Management, where risks associated with the implementation of Lean Management in Technology Management are discussed. In contrast to the risks, Chapter 3.4.3.3 Opportunities in application of lean methods, principles in Technology Management, highlights the opportunities related to the application of Lean Management in Technology Management. Finally, Chapter 3.4.3.4 Lean principles and methods for Technology Management, presents the survey results regarding the application of Lean Management methods and principles in the various phases of Technology Management.

3.4.3.1 Greatest potentials with lean thinking in Technology Management

The inquiry into the foremost potentials in Technology Management, specifically in the context of applying lean methods and principles, poses a nuanced challenge. Nevertheless, valuable insights from interview participants can be succinctly summarized as follows. Companies E and H identify the most significant potential in enhancing efficiency through the implementation of Lean Management across the entire Technology Management process. By placing a central focus on the customer and streamlining towards essential elements, the actual value for the customer takes center stage. Company H emphasizes this alignment with lean thinking: "*However, a key aspect that aligns with lean thinking is how to efficiently achieve the goal once we understand market needs and competitive positioning. That is certainly a point of focus.*" Taking a broader perspective, Company T asserts that Lean Management inherently recognizes potentials and triggers improvements. This applies not only to Technology Management but extends to all corporate processes, as stated by Company T: "*Lean Management compels me to evaluate processes from the customer's perspective. If this is truly embraced, it becomes a key driver for success.*” Additionally, Companies R and X posit that openness to change through customer focus, facilitated by Lean Management, is the key to success. This involves a continuous questioning of whether the right things are being done and a steadfast examination of issues from various perspectives. Companies AB and AC recognize another potential, seeing the central value in the standardization of processes. However, it is acknowledged that there must be room for controlled waste, especially in the early phases of Technology Management. It requires a playground and targeted application of Lean Management methods where they make sense. Notably, Company F contends that the utilization of Lean Management allows the assimilation of insights into the Technology Management process more efficiently. This confers a decisive advantage, enabling subsequent developments to commence at a significantly advanced stage compared to without this feedback loop.

Technology detection – In the early phases of Technology Management, companies perceive the opportunity to establish necessary transparency through Lean Management. Company AC suggests that there are often overly enthusiastic approaches from individuals toward new technologies. The consequence is impulsive decisions based not on facts but on the emotions of a few individuals at the moment. The lean mindset aims to present information in a fact-based manner for decision-making. Consequently, utilizing lean methods can lead to targeted advancements and improvements by fostering a better understanding of the application context and the underlying issues. Furthermore, Companies O and Z emphasize the importance of installing a lean filter in this context. This filter should only allow technologies that can generate significant benefits for the customer, thereby preventing the development of unnecessary features. In conclusion, while deliberate work is crucial, Company N asserts that allowing so-called storming phases is permissible.

Technology planning – In the technology planning phase, companies consider prioritization to be essential. Company W suggests that this prioritization can be standardized through lean thinking. Furthermore, Companies N and W view the "*fail fast, fail cheap*" principle as a highly efficient concept, particularly in the context of technology planning. In line with the MVP approach, Lean Management can bring about efficiency improvements. The objective is to have clarity in the planning phase regarding the extent of technology development and how market validation through MVPs can provide insights. Additionally, Companies D and N see the potential in having a clear plan that highlights market-dependent opportunities and risks. Adaptation activities for entering additional markets should also be considered if the technology proves successful.

Technology development – In general, it can be stated that some companies see significant potential in technology development. Company D, for example, believes that substantial investments are necessary during the development phases to enable the most efficient utilization phase. As the resulting products typically remain in the market for years, this represents a significant lever for optimization. This is envisioned through standardization activities in development. Additionally, Company Y observes, "*In the* *realm of technology management, particularly within research and development – encompassing both product and process development – the significance is undeniable. Working within an equipment-intensive industry, it's observed that around 80% of the problems encountered later in the production process or with the final product are rooted in the early design phase.*" It is essential to focus on aspects such as availability, ease of maintenance, safety, and reliability during the development phases. To minimize later inefficiencies, substantial intellectual efforts in the early project phases are indispensable. Even though quantifying the impacts of avoidable damages is challenging, this underscores the importance of strategic resource allocation and thorough planning at the outset to mitigate potential issues and reduce long-term inefficiencies. Company K emphasizes the feedback of learnings into technology development, while Company G takes it a step further, improving planned processes and products virtually through simulations before investing in facilities, using Lean methods. Furthermore, the inclusion of all interfaces and stakeholders, such as suppliers, can unlock additional potentials. Company I anticipate a reduction in time-to-market through the application of Lean methods in this process, and Company S highlights the importance of interfaces and seamless communication, where Lean Management can also prevent waste.

Technology exploitation – In this phase, it is of paramount importance to efficiently implement the developed technologies and the resulting products and processes. Various findings indicate that this implementation phase offers the highest density of opportunities for applying lean methods. Company Z characterizes this phase of execution as the integration of technology into the corporate DNA. This implies that the new technology must be accepted by employees to be effectively and efficiently applied. It is advisable to employ lean methods here, as they contribute to standardization and error avoidance. As emphasized by Company F, "*Standardizing at this point is the most effective way to achieve efficiency. However, there are significant risks involved. If individuals are not properly engaged, trained, and carried along, rejection may occur. The success of the overall process, including the launch and deployment of new technologies, heavily relies on standardized approaches. This* *includes clear goals defined at each gate and a structured launch process rather than relying on ad hoc actions.*" Furthermore, Companies F, Z, and AA are of the opinion that the focus here should be on process optimization. However, it is worth noting that the scope for changes to products and processes is limited. Company K underscores this by stating, "*Any change would require requalification, and there are cases where we have developed products without regard to manufacturing efficiency.*" For this reason, it is mentioned that lean methods must already be applied in all early phases. Companies V and P see significant potential for optimization through various lean methods in technology exploitation. Company Q shares a similar view, but it specifically identifies the greatest potential in combining Lean Management with artificial intelligence. The aim is to delegate routine tasks in technology exploitation to artificial intelligence, thereby unlocking potential for efficiency improvements.

Technology protection – No explicit potential was outlined in the domain of technology protection. Instead, the focus was solely on referencing synergy effects arising from enhancements in the overall Technology Management process.

Technology assessment – The identification of technology assessment as a focal point for the application of lean methods was uniquely emphasized by Company A. However, it is noteworthy to recognize that across diverse contexts, as expounded in other sections, numerous companies acknowledge the intrinsic importance and feasibility of integrating lean methods within the domain of technology assessment. As an illustrative example, the imperative role of standardization in the evaluation process is universally acknowledged across different phases. Company A introduces an evaluative paradigm wherein technologies are scrutinized based on their lean grade, serving as a mechanism to gauge the potential leanness of resultant products and processes.

3.4.3.2 Risks in application of lean methods, principles in Technology Management

Companies express diverse views and concerns regarding the implementation of lean methods in Technology Management. Some caution against the risk of employee disengagement with an extensive adoption of lean practices, emphasizing that simplicity often correlates with less proactive thinking, as articulated by Company C. On the other hand, there are concerns about an overemphasis on efficiency that might stifle innovation and restrict the exploration of groundbreaking ideas. Striking a balance between standardization and adaptability is considered crucial, with acknowledgment of potential risks of excessive standardization, such as unnecessary complexity and limited fulfillment of specific requirements. As an example, Company F states, "*There are risks associated with standardization as well. It's possible to over-standardize, leading to unnecessary complexity and effort that may not yield proportional benefits. The challenge is to strike the right balance and avoid excessive standardization, especially when the effort outweighs the perceived benefits.*" Company I highlight risks in measuring the impacts of lean methods in Technology Management, especially in abstract areas. Clear measurability is crucial to transparently present successes or failures. Cultural resistances and the potential hindrance of employee innovations are concerning, particularly when attempting to integrate innovative individuals into streamlined processes, as expressed by Company F. Furthermore, Company J notes that a narrow focus on new technologies in early detection may overlook new business opportunities. Company K explains that since Lean Management is highly customer-oriented, some products might not be developed because the customer does not perceive them as important, although other customers might: "*We discovered another sector with an urgent need for the sensor. If I had solely considered it from a cost-efficiency perspective, I might not have pursued its development.*" There is consensus that a lean approach should not overshadow the need for foresight and creativity and should be applied deliberately where it makes an effective contribution. However, it should be noted that Companies G and AA see almost no risks in the application of lean methods in Technology Management. In conclusion, the mentioned risks underscore the importance of a balanced and thoughtful approach in implementing lean methodologies in Technology Management, considering the unique contexts and challenges of each organization. The risks are listed again below:

- Over standardization and lack of adaptability: Excessive standardization of processes can lead to unnecessary complexity and restrict adaptability to specific requirements. Finding a balance is crucial to avoid excessive standardization.
- Overlooking new opportunities: The risk of overlooking opportunities due to a narrow focus. For example, new business areas that could be explored with emerging technologies.
- Innovation restriction through efficiency focus: Exclusive emphasis on efficiency can limit innovative thinking. Striking a balance between efficiency and fostering creativity is crucial.
- Challenges in measuring impact: Measuring the impact of lean methods, especially in abstract areas, can be challenging. Estimations and network effects must be considered.
- Cultural resistance and employee innovation: Overemphasis on lean practices can stifle innovative thinking, and employee resistance can limit the successful implementation of lean methodologies.
- Profitability vs. job loss: Streamlining processes for increased profitability may lead to job loss, presenting both opportunities and challenges in talent acquisition and upskilling.
- Overemphasis on cost-cutting: Excessive focus on cost-cutting can lead to shortages and hinder normal operations. Striking a balance is crucial to avoid excessive leanness leading to losses.
- Perception of lean as passing trend: Employees may resist lean initiatives if they perceive them as passing trends imposed by management without engagement and understanding.
- Risk of imposing systems without understanding implications: Implementing lean systems without thorough evaluation and understanding of control variables may lead to resistance and failure.
- Customer-centric approach vs. rigid processes: Rigid processes may lead to the loss of customers if they don't align with specific needs. Maintaining a healthy balance and flexibility is crucial.

3.4.3.3 Opportunities in application of lean methods, principles in Technology Management

Here, all mentioned opportunities are highlighted that companies see in the application of lean methods or principles in Technology Management. Company AC sees potential in targeted bundling of resources and knowledge. This knowledge should then be standardized to increase overall productivity in the process, ultimately enhancing the long-term competitive advantage. Company C states, "*The potential benefits of incorporating lean practices include increased efficiency and error prevention.*" Additionally, Company J notes that Lean Management in Technology Management, with its continuous improvement mindset, focuses on optimizing processes and can make a valuable contribution. The emphasis is on ensuring timely availability of the right technologies while balancing performance and cost-effectiveness. Company D asserts that the opportunities in Lean Management in Technology Management lie in time-to-market, enabling quick responses to changes, especially in requirement modifications. Companies Y and AB believe that Lean Management can increase objectivity in evaluation due to its fact-based nature, making gut decisions secondary. Furthermore, they mention that efficiency improvement and systematic elimination of inefficiencies are the focus. Companies aim for rapid market entry, swift response to changes, and the use of structured methods, based on a predefined toolbox from Lean Management. Company M claims, "*The chance is that you are more efficient. If you approach it in a structured way, you have a method to better assess the risk or market viability.*" Additionally, Companies E, F, K, P, and AA highlight the clear advantage of the enforced, structured path in development through standardization, leading to higher efficiency. They also mention standardization in the product portfolio through a modular system and a standard catalog, reducing efforts and avoiding starting from scratch. The integration of Poka Yoke in product development is recommended, and continuous improvement, and problem-solving are considered integral for success. Furthermore, there are potentials in aligning technologies precisely with market requirements and their efficient implementation. Below, the opportunities are listed again:

- Process structures and standardization: Opportunities arise through specific process structures with a focus on bundling resources and standardizing knowledge to enhance productivity. Additionally, the integration of Poka Yoke in product development is recommended, and continuous improvement and problem-solving are considered integral to success.
- Building block system and standard catalog: Efforts are reduced, and development doesn't always start from scratch. Moreover, the risk decreases due to the experiential knowledge embedded in the catalog.
- Toolbox: Lean Management serves as a toolbox that can be strategically employed in Technology Management.
- Efficiency improvement and inefficiency elimination: Benefits of integrating lean methods include increased efficiency and error prevention. Emphasis is placed on the timely availability of the right technologies, considering performance and cost-effectiveness. The focus is on time-to-market, quick response to changes, and systematic elimination of inefficiencies through the application of lean methods.
- Increase in objectivity: Lean Management is highly fact-based, providing clear support in evaluating new technologies to reduce decision-making errors.

MVP Minimum Viable Product – Furthermore, some companies have highlighted the importance and efficiency of the MVP. This concept in Technology Management, combined with Lean Management, can bring significant advantages. The primary goal is to gain certainty about customer acceptance and the product's relevance, thereby improving the estimation of its potential. Company S states: "*This approach acknowledges the reality that companies often have to work with limited resources while needing to react quickly and effectively to the market.*" By focusing on the essentials and employing short iteration loops, efficient progress toward the goal can be achieved. Supported by rapid prototyping, a functional prototype can be created, and valuable feedback can be incorporated through targeted market surveys, initiating optimizations. This approach aims to optimize time-to-market and ensure that resources are used efficiently.

Table 15 below provides an overview of the risks and opportunities in the application of lean methods and principles in Technology Management. An attempt is made to highlight the most important risks and opportunities in each case.

Risks in application of lean methods, principles in Technology Management	**Opportunities** in application of lean methods, principles in Technology Management
Over standardization and lack of adaptability Excessive standardization of processes leads to limited adaptability and increased inertia when changes are necessary.	**Process structures and standardization** Focus on bundling resources and standardizing knowledge to enhance productivity. Targeted and structured integration of information into processes.
Overlooking opportunities, innovation restriction through efficiency focus Too narrow a focus can lead to opportunities not being recognized, both within and outside the environment or market.	**Building block system and standard catalog** Development starts at an advanced stage by reduced efforts. Reduction of risks by using of proven systems.
Challenges in measuring impact Measurability of activities is sometimes difficult to quantify, so it is important to ensure that subjectivity is clearly represented.	**Toolbox for selecting lean methods** Application of defined methods according the Advanced Lean Technology Management Model.
Cultural resistance and employee innovation, perception of lean as passing trend without understanding implications Flexibility in the application of lean methods and clear goals in combination with full understanding of the methods is crucial.	**Efficiency improvement and inefficiency elimination** Increasing efficiency by reducing errors. Focus on time-to-market and quick reaction on customer needs.
Profitability vs. job loss, overemphasis on cost-cutting Transparency in the presentation and highlighting opportunities for employees promotes motivation.	**Increase of objectivity** A fact-based evaluation leads to a rational assessment, which in turn results in fewer wrong decisions.
Customer-centric approach vs. rigid processes Processes that are too "standardized" with less flexibility lead to rigidity. Customer orientation is always the key and should be the top priority.	**Using MVP for continuous improvement** Short loops and fast feedback lead to a high degree of certainty regarding acceptance and relevance for the customer.

Table 15: Overview of risks and opportunities in application of lean methods, principles in Technology Management

3.4.3.4 Lean principles and methods for Technology Management

During the interviews, the lean principles defined in Chapter 2.4.2 Clustering of lean methods to principles were explained to the interviewees. An overview of these principles can be seen in Table 16. Furthermore, the applicability of these principles in the various Technology Management phases was inquired about afterwards. The results of this survey can be found in Table 17.

Standardization & structuring (A)	Stands for an increase in transparency and creates an environment of confidence
Focusing & professionalization (B)	Stands for concentration on the essentials with a central focus on the customer
Continuity & sustainability (C)	Stands for future orientation with the goal of improving step by step
Failure prevention (D)	Stands for the increase of quality and the reduction of risks

Table 16: Overview of lean principles

The selection of these four principles shown in Table 16 is justified by their fundamental roles across various domains and their interrelatedness. Standardization & structuring (A) are essential for rationalizing processes and ensuring consistency. Focusing & professionalization (B) enhance effectiveness by setting clear goals and developing expertise. Continuity & sustainability (C) are crucial for long-term success by ensuring stability and considering ecological and social aspects. Failure prevention (D) is necessary to maintain quality and trust by identifying and rectifying errors early. While other principles could be considered, these four are deemed essential for achieving the outlined goals and working synergistically to drive organizational success.

It can be observed that technology exploitation is the phase with the most intensive applicability, encompassing all four principles. This is followed by technology planning and technology development, each emphasizing three principles. In technology planning, the focus is on principles A, B, and C, while in technology development, the emphasis is on principles A, B, and D as well. Furthermore, at a similar level, both technology detection and technology assessment exhibit application of two principles each. For technology detection, the focus is on principles B and C, whereas for technology assessment, the focus is on principles A and B. The surveyed companies perceive the lowest applicability in technology protection, with the focus on a single principle, namely B.

	Lean principle			
Technology Management Process Phase	A	B	C	D
Technology detection	○	●	●	○
Technology planning	●	●	●	◑
Technology development	●	●	◑	●
Technology exploitation	●	●	●	●
Technology protection	◑	●	○	○
Technology assessment	●	●	◑	◑

Standardization & structuring (A)
Focusing & professionalization (B)
Continuity & sustainability (C)
Failure prevention (D)

Applicability:
○ bad
◑ neutral
● good

Table 17: Applicability of lean principles in the individual Technology Management process steps

Table 17 shows the results of the conducted expert interviews, for additional validation and confirmation of the obtained results, several illustrative examples are subsequently presented. These examples are categorically assigned to the six constituent sub-processes of Technology Management as follows:

Technology detection – For instance, Company E emphasizes that the identification phase involves a meticulous consideration of genuine necessities, indispensable technologies, and those deemed superfluous. This involves narrowing down the focus to increase efficiency by pursuing only the technologies required to meet customer demands. Company J, exemplifying a scientific approach, underscores principle C as an indispensable factor in technological foresight. This assertion is grounded in the understanding that the company's enduring prospects hinge on strategic initiatives within this domain. Company Q articulates a proactive stance, stating, "*We actively engage in the pursuit of emerging technologies, with a primary objective of optimizing our responsiveness to customer needs and thereby securing a competitive advantage over industry peers. [...] Our overarching emphasis remains steadfastly on the concrete benefits accruing to our customer.*"

Technology planning – Companies G and H exemplify that principle A is advantageous in technology planning, especially in assessing efforts and resources for implementation. This allows for easier access to experiences. Additionally, Company N emphasizes the importance of principle B, noting that only topics needed by the organization should be introduced and planned. Furthermore, Company V recommends principles A and C, stating, "*The emphasis on A and C is rooted in the necessity to track progress and create a structured plan. A clear plan enables targeted actions and ensures decisions are not arbitrary but guided by a strategic path. In my opinion, this is essential to remain competitive in the market and understand the long-term evolution of technology. It is the cornerstone of effective and meaningful technology planning.*"

Technology development – Company D asserts that principle A, particularly in the context of modularization within the development process, holds significant importance. This strategic approach also facilitates measurability through the assessment of reuse rates, which are actively quantified. Moreover, Company F observes that the implementation of principle A in this phase leads to a substantial reduction in development times. Additionally, Company M underscores the importance of principle B, emphasizing the need to sustain the customer-centric focus initiated during the planning stage. Development activities are aligned with explicit customer requirements. Furthermore, Company Q regards principles C and D as indispensable during the development phase. This is driven by the dual objectives of enhancing quality and mitigating risks, as well as recognizing the imperative role of continuous improvement in advancing technology development.

Technology exploitation – All four principles are intended to be applied in technology exploitation, as emphasized by the majority of companies, including Company G, stating: "*Certainly, A, which emphasizes standardization, is of fundamental importance. This includes the introduction of performance indicators and various standardizations. Performance metrics are crucial in this context. B, the consistent focus on customer benefit and ensuring compliance with the original requirements, requires continuous evaluation to keep an eye on customer needs. Therefore, C remains undeniably a key focus. And D is also significant in this phase.*" Additionally, Company P emphasizes that standardization, principle A, is crucial when implementing technologies into products and processes. However, it is also important to focus on the customer to operate as efficiently as possible. Company R further asserts that in daily work, gradual improvement and the corresponding assurance of quality are essential focuses, thus considering principles C and D as relevant. Company V finds it sensible, when it comes to technology utilization, that principle A establishes a consistent and reliable process, supplemented with principle D to ensure error prevention using the example of Poka Yoke.

Technology protection – Illustratively, Company H argues as follows: "*In the context of technology protection, it seems that error prevention and proving step-by-step may not be as directly applicable. However, focusing becomes a crucial aspect, especially when it comes to intellectual property (IP) and know-how protection. Concentrating on where to place the emphasis in terms of IP and know-how protection is essential to avoid getting overwhelmed.*" This approach is considered highly important for cost-effective operations. Another example highlighting the focus on principle B is described by Company R. By emphasizing the cost-intensive nature of actions in e.g., patent system, it is crucial to operate with focus and concentrate on the essentials. Acting not excessively but purposefully is the key. Company W underscores this with the statement: "*It's about understanding what exactly we need to protect primarily because protecting everything doesn't necessarily benefit us.*" Additionally, Company AA emphasizes that only truly important matters should be protected, as secondary issues are irrelevant.

Technology assessment – Company G articulates the significance of principles A and B by stating, "*If assessments or reviews are consistently conducted according to disparate standards, comparable results become unattainable. B is equally pivotal as it aligns with the essence of Principle B, prompting the logical examination of whether the established goal remains appropriate.*" In a parallel vein, Company H espouses a perspective, highlighting the necessity for a standardized lens when appraising attained outcomes. Consequently, the utilization of standardized metrics, coupled with a focused approach, becomes indispensable for the evaluation of dedicated objectives. Company

M underscores the importance of objectivity in assessments, deeming a focus on principle A as crucial. Furthermore, Company Q asserts that the objective in evaluations is to compare everything on a factual basis, thus averting the possibility of making wrong decisions. Simultaneously, it is crucial to keep an eye on the essential aspects, as that is what the customer pays for.

Overall rating – In-depth analysis of the overarching survey regarding the applicability of lean principles in individual Technology Management phases involved explicit inquiries about the applicability of specific lean methods, as listed in Table 4, in those phases. The results of this survey, sorted by highest applicability, are depicted in Table 18. The survey was based on an initial assessment of the applicability of each lean method in the respective Technology Management phase, as shown in Table 6. Interview participants were presented with this initial assessment, and their task was to mark and reassess positions with which they disagreed. The results of this survey are presented in Table 18. It is evident once again that the clear focus of applicability for lean methods lies in technology exploitation, followed by technology planning and technology development. Additionally, technology detection and technology assessment show similar levels of applicability, with technology protection trailing behind.

Furthermore, it is noticeable that among the top ten lean methods from Figure 15 and Table 18, there are overlaps. The following six methods consistently appear in the top ten for each respective phase: Visual Control system via KPIs, Kaizen/CIP, Failure Mode Effects Analysis, Five Whys, Pareto, and 5S. Consequently, these methods exhibit a strong presence and applicability across the respective themes. Table 18 shows the results of the conducted expert interviews.

Lean method Sorted by highest applicability	**Technology detection**	**Technology planning**	**Technology development**	**Technology exploitation**	**Technology protection**	**Technology assessment**
Visual Control system via KPIs	●	●	◐	●	●	●
Kaizen/CIP	◐	●	●	●	◐	◐
Failure Mode Effects Analysis	◐	◐	●	●	○	●
Five whys	●	◐	●	●	○	●
Pareto	◐	●	●	●	◐	◐
5S	◐	●	◐	●	○	●
Gemba	●	◐	●	●	○	◐
7 wastes	○	●	●	●	○	◐
Poka Yoke	◐	◐	◐	●	◐	◐
Theory of Constraints	◐	◐	●	●	○	◐
Quality Function Deployment	◐	●	●	◐	○	◐
Kanban	○	●	◐	●	○	◐
Total Productive Maintenance	◐	●	●	◐	◐	◐
Just in Time	○	●	◐	●	○	○
ABC	●	◐	◐	●	◐	◐
Overall Equipment Effectiveness	○	◐	◐	●	○	◐
Total Quality Management	◐	◐	●	●	◐	◐
Value Stream Mapping	◐	●	◐	●	○	◐
Six Sigma	◐	◐	◐	◐	◐	◐
Jidoka	○	◐	○	●	○	◐
Single Minute Exchange of Die	○	◐	●	◐	○	◐

Applicability:
○ bad
◐ neutral
● good

Table 18: Applicability of lean methods in the individual Technology Management process steps

3.5 Design of a Lean Technology Management Model

Based on the questionnaire provided in the appendix, various aspects of the model's content were discussed incrementally. Questions 9, 10, and 11 specifically addressed the model depicted in Figure 12. The model was explained comprehensively, covering all existing components, to ensure clarity for the interview participants regarding the understanding of each term. The following outlines the gathered insights, starting with the challenges in Chapter 3.4.4.1 Challenges in applying the model, followed by the advantages in Chapter 3.4.4.2 Advantages in applying the model. The conclusion is presented in Chapter 3.4.4.3 Suggestions for improvement of the LTMM, where additional proposals for enhancing the model are provided.

3.5.1 Challenges in applying the model

Here, all challenges related to the application of the model are presented. It is crucial that the discussion is based on the model depicted in Figure 12. Almost all companies consider employees as the most important factor or the biggest challenge. It is crucial to engage employees, especially key players, and thus increase their readiness for change. Any change typically encounters resistance, which needs to be overcome as efficiently as possible to persuade employees to accept the change. This is only possible with effective change management, as asserted by Companies Q, W, and Y. In this context, Company O explains that intensive persuasion is necessary to get employees to accept the change. Furthermore, Companies F, T, and L emphasize that a cultural shift is required to implement this combination of topics. Company T describes it as follows: "*Primarily, it's about a cultural shift. This means that people need to learn something new. They need to apply and persevere, and we know from experience that it takes about twelve to fourteen presentations and internal instructions in our company until something is reasonably established. It's also of no use if the board or owners support it.*" Another significant challenge is mentioned by Company E: "*The challenge is to convey that such models, although theoretically complex, make sense. Often, the* *difficulty lies in conveying to people how important a systematic approach is and how theoretical models can achieve this.*" It is crucial to reduce complexity and choose a clearly understandable language. An example of this would be to perform preparatory work and conduct Lean Management training as a foundation in advance. In this context, Company H mentions: "*Precisely because there are so many different principles and so many steps to assess in this process, and when you put the whole thing into a corporate context, someone who has to do this now - in our case, it's about the introduction of Lean Technology Management - quickly feels lost because the matter is very complex, especially if they haven't been dealing with it for long.*" For this reason, Company V supports the approach of breaking down such a complex model into small steps and defining a gradual plan with dedicated small goals and successes. Companies C, E, and W also emphasize the need to structure the intensive initial efforts and endeavors so that they consistently result in small victories. This is the only way to maintain employee motivation. Additionally, Companies Y and AC mention that the term lean itself could be a problem, and therefore, a different name should be considered. In this context, Companies B and G point out the dosage of Lean Management as a potential challenge. Company G emphasizes this with: "*This approach is in line with the idea that excessive streamlining, even to outsourcing, can lead to unintended negative results. Therefore, it is important to avoid such extremes and pursue a balanced strategy for sustainable development.*" Company R mentions here that the topic of Lean Management is only familiar to many from production, and therefore, the possible extensions need to be well explained. Company D also mentions that depending on the size of the company, different challenges arise. Company P emphasizes that the high number of interfaces requires excellent coordination and organization in the introduction, especially concerning all other business processes in a company. This following list summarizes the multifaceted challenges:

- Employee engagement and resistance: Convincing employees, especially key players, and overcoming resistance to increase their acceptance of change.
- Effective change management: Implementing effective change management strategies to facilitate a smooth transition.

- Cultural shift: Navigating and promoting a cultural shift within the organization to align with new models and approaches.
- Communication and persuasion: Conducting intensive persuasion to convey the importance of theoretical models and the systematic approach to employees.
- Complexity reduction: Reducing the complexity of models and topics to make them more understandable for all stakeholders.
- Training and preparation: Providing adequate training, such as Lean Management sessions, and conducting preparatory work for a solid foundation.
- Motivation maintenance: Structuring initial efforts and endeavors to consistently achieve small victories and maintain high employee motivation.
- Naming and terminology: Addressing challenges related to the term "lean" and considering alternative names to better communicate the concept.
- Dosage of Lean Management: Balancing the implementation of Lean Management to avoid potential negative consequences, such as excessive streamlining.
- Understanding and explaining extensions: Ensuring that employees understand the extensions of Lean Management beyond its traditional association with production.
- Different challenges based on company size: Acknowledging that the challenges may vary depending on the size of the company, requiring tailored approaches.
- Coordination and organization: Managing a high number of interfaces that necessitate excellent coordination and organization, particularly concerning other business processes.

3.5.2 Advantages in applying the model

All advantages related to the application of the model in businesses, as depicted in Figure 12, are summarized here. It should be noted that the interviewed companies have received the created model very positively. The majority of firms have mentioned efficiency improvement as a potential benefit. The model aids in efficiently achieving technological goals; Company E emphasizes this by stating, "*I believe that Lean*

Technology Management makes sense for me fundamentally because it streamlines and makes the entire process of Technology Management, we've seen more efficient. I think this is valuable for companies in general. While many acknowledge the existence of waste and the need for efficiency through standardization, I believe there is a lack of both a systematic approach and methodology. These could be integrated into thinking with the model." In this context, companies P and S see that the structured and standardized representation or approach increases effectiveness and efficiency. They also mention that other business processes can be optimized on a similar basis, reinforcing through exemplary application in Technology Management. The majority of companies further find that the model generates a comprehensive overview and thus provides a clear structure for the organization. This enhances transparency and accountability for responsibilities. Company I confirm this with: "*The benefit, in my opinion, certainly lies in the comprehensive overview and transparent representation of Technology Management in the company. It is an essential goal not just to treat technology as a byproduct but to integrate it into the core strategy of the company.*" Furthermore, companies D and W note that time-to-market can be reduced through this standardization. Emphasizing customer-focused alignment, Company P stresses that this enables sustainable business development. Additionally, flexibility in responding to market influences and changing customer needs can be achieved through increased productivity, creating competitive advantages. In this context, companies D and F also see an advantage in sustainable competitiveness. The overall innovation performance of the company increases through the application of the model, as highlighted by companies U and Z. It promotes the goal of having the right technology available at the right time, as expressed by Company U. Furthermore, companies S and AA mention an increase in precision in technology decisions. The transparent and standardized approach minimizes the risk of mistakes. In this regard, Company T sees an increase in quality in the results. The representation or the underlying information also forms a knowledge database. Companies H and L mean that this defined method pool is available for different areas, specifying where methods or principles should be applied. Company H believes that the resulting documentation supports the identification of further improvement potentials. Therefore, advantages in quality arise, fostering technological progress, as claimed by Company D. In conclusion, these benefits translate into a monetary advantage, as affirmed by Company M: "*It should result in lower development costs, higher customer satisfaction, and consequently, increased revenue and profits.*" This following list summarizes the multifaceted advantages:

- Efficiency improvement: The model is widely recognized for its potential to enhance efficiency, with many companies citing it as a significant advantage.
- Streamlined Technology Management: Lean Technology Management provided by the model streamlines and improves the entire process of Technology Management.
- Structured and standardized approach: The structured and standardized representation offered by the model increases effectiveness and efficiency.
- Versatility across business processes: The model's optimization potential extends beyond Technology Management, showcasing adaptability to other business processes and strengthening overall organizational efficiency.
- Comprehensive overview: The model generates a comprehensive overview, providing organizations with a clear structure, fostering transparency and accountability for responsibilities.
- Integration of technology into core strategy: The model's role in integrating technology into the core strategy of the company, emphasizing its significance beyond being a byproduct.
- Reduced time-to-market: Reduction in time-to-market through the standardized approach, enhancing the company's ability to bring products to market more quickly.
- Customer-focused alignment: Aligning with customer needs, the model enables sustainable business development and flexibility in responding to market influences.
- Competitive advantage: Increased productivity creates a competitive advantage by allowing flexible responses to changing customer needs and market dynamics.

- Enhanced innovation performance: The application of the model leads to an overall increase in the innovation performance of the company.
- Precision in technology decisions: Improvement in the precision of technology decisions through the transparent and standardized approach, minimizing the risk of mistakes.
- Quality improvement: Increase in the quality of results, emphasizing the positive impact of the model on the outcomes of various processes.
- Knowledge database creation: The model's representation and underlying information serve as a knowledge database, providing a defined method pool for different areas.
- Identification of improvement potentials: The resulting documentation supports the identification of improvement potentials, enhancing overall quality and fostering technological progress.
- Monetary benefits: Ultimately, these advantages contribute to a monetary gain, including lower development costs, higher customer satisfaction, and increased revenue and profits.

3.5.3 Suggestions for improvement of the LTMM

General suggestions: A fundamental and significant point raised by Company W is the need to ensure measurability of actions and activities concerning the recommendations resulting from the model. While metrics such as time-to-market may serve as quantifiable indicators, there remains a notable risk of subjective perception unless compared with empirical data. Additionally, Company H notes that the model appears highly complex at first glance, suggesting it would be helpful to specify actionable recommendations. This implies a desire for a “First Steps Plan” to introduce such a model or an indicator highlighting the most crucial topics. The maturity level of an enterprise emerges as another salient determinant. Company H mentions that a company's focus varies depending on its maturity level, necessitating different approaches to implementing the model. In this context, Company V adds that it may not be feasible for all companies to introduce such a model due to interactions and complexity. Company AB underscores the strategic utility of an MVP in expediting the acquisition of customer feedback. Furthermore, Company P underscores the foundational role of vision and strategy, although these elements are not explicitly evident in the model. While the model is geared towards the concept of a Lean Company, not every company shares the goal of becoming one. Hence, Company G mentions that the dosage of lean is crucial, stating, "*The dose makes the poison. And there's a very fine line between thin and unhealthy, or lean and malnourished.*" Another very essential topic is the prevailing culture within an organization and the associated challenges. For instance, Company Q believes that the associated process is very time-intensive. Furthermore, transitioning to a Lean Company can only occur gradually, in order to achieve a sustainable outcome. Finally, companies highlight the importance of clearly explaining the terms used, as they may not be self-explanatory.

Graphical suggestions: Here are excerpts of the graphical improvement recommendations concerning to the model presented in the interviews. The model is shown in Figure 12. Company L advises a redesign of the corporate development theme, enhancing clarity regarding its integration and positioning within the overarching context. Additionally, due consideration should be given to environmental influences, particularly environmental catastrophes, with a heightened focus on their correlation to potential business risks. Company M proposes a graphic enhancement by incorporating a cyclic structure, thereby establishing an iterative improvement cycle. Subsequently, numerous companies express a need for insights into additional business processes, which are not evident within the existing model. Company N underscores the pivotal role of trends or megatrends as a crucial environmental sphere, given their substantial impact on technology-related decisions. Furthermore, Company O observes a potential interpretation of the illustration as both a 2D and/or 3D representation. A relevant observation from Company S centers on the stakeholders within the illustration, highlighting ambiguity regarding the distinction between internal and external stakeholders. Finally, it is noteworthy that, among others, Company AB advocates a pronounced customer-centric focus, a perspective that should manifest as the central orientation of the model.

Part IV

Discussion and Conclusion

4 Discussion of Findings, Conclusion, and Implications

4.1 Aims and Structure of the Chapter

Chapter 1 Research Intent, provides an overview of the structure, content, and research questions of this study. Chapter 2 Theoretical Background and Concept of the LTM-Model, delves into the existing knowledge pertaining to the two core themes and presents a theoretical concept of the LTMM. Chapter 3 Empirical Research, details the collection of empirical data and examines and tests the adapted model. Following this, in Chapter 4 Discussion of Findings, Conclusion, and Implications, the juxtaposition of theory and empirical findings occurs, accompanied by the description of the Advanced Lean Technology Management Model. Additionally, a summary description of the results and explanations of theoretical and practical implications are provided. Finally, Chapter 5 Summary and Outlook, offers a concise overview of the study, practical recommendations, limitations, and suggestions for future research endeavors.

4.2 Lean Management and Technology Management

In Chapters 2.2 Lean Management and 2.3 Technology Management, I discussed the current understanding of Lean Management and Technology Management according to the literature in both fields. The following sections, Chapter 4.2.1 Lean Management and 4.2.2 Technology Management, will juxtapose the empirical knowledge described in Chapter 3.4 Empirical Findings with the adapted framework.

4.2.1 Lean Management

Lean Management is undoubtedly widely practiced in the field, but understanding of it is by no means uniform. Companies often have differing views and approaches to the subject, leading to diverse treatment within the organization. With regard to the empirical findings in this chapter, I refer to section 3.4.1 Organization of Lean Management. While current literature does not describe negative emotions associated with the term lean, many companies perceive this as a significant issue. Experiences show that in the course of lean projects, staff reductions have occurred, leading to negative emotions. For this reason, many companies use alternative terms such as OPEX or Performance Engine for Lean Management.

Another issue arises from the incorrect application of lean methods or techniques, which can cause frustration mistakenly attributed to Lean Management. However, this frustration often stems from a different cause, namely, lack of methodological competence. The literature emphasizes the importance of the proper application of methods and techniques and that Lean Management is valuable not only for operational areas but for the entire company. Although most companies agree with this, Lean Management is still mainly used in the operations area. This is also evident from the survey on specific lean methods, see Figure 15. It is clear here that more methods are known than are actually applied. Thus, it can be concluded that often there is a belief that one is familiar with a method when this is not the case.

It is not yet widely recognized that Lean Management pursues a holistic approach and is no longer just a tool for the shop floor (James P. Womack, Daniel T. Jones, Daniel Roos, 1990). However, some companies are already optimizing additional areas of the business with Lean Management. The literature highlights Lean Management's focus on waste reduction and non-value-added activities, while this is not clearly evident in empirical data. Nevertheless, in practice, customer focus is considered a priority, even if it does not precisely match the descriptions in the literature.

In summary, it can be said that some companies correlate more strongly with existing knowledge than others. However, there is a clear alignment between existing knowledge and empirical findings in the area of necessary cultural changes within a company to successfully implement Lean Management holistically.

4.2.2 Technology Management

In numerous corporate contexts, the pivotal role of Technology Management in fostering sustainable business development is widely acknowledged. Nevertheless, a prevalent issue persists in the lack of precise definition and differentiation of distinct phases, as delineated by Schuh and Klappert (2011) or Gregory (1995). Consequently, there's uncertainty about when certain Technology Management activities should be undertaken. Thus, there's a pressing need for clear terminology within companies, as these terms are not self-explanatory. According to the literature, it is not apparent that this knowledge is not yet widespread in many companies.

While literature describes a clear distinction between Research and Development (R&D) management, Innovation Management, and Technology Management, in practice, these concepts often overlap and are used interchangeably. This blurring of boundaries makes it challenging for companies to implement structured approaches effectively, despite many emphasizing the importance of structured methodologies in this domain.

It becomes evident that Technology Management interfaces with various areas within companies, a fact supported by empirical data. Companies recognize significant potential here for efficiency improvements. Looking ahead, companies will require a high degree of flexibility, as supported by empirical evidence, particularly concerning rapid market feedback. There's consensus regarding the importance of aligning strategies with corporate objectives to ensure sustainable competitiveness. Employees play a crucial role in this domain as carriers of know-how for the sustainable development of the company.

In summation, Technology Management emerges as the cornerstone underpinning prospective innovations within organizational frameworks.

4.3 Lean Technology Management as an advanced concept

The sustainable integration of both management disciplines requires a fundamental understanding of each field. Lean Management should not be regarded merely as a simple toolkit of methods; rather, it necessitates the adoption of the mindset, fundamental attitudes, approach, and associated decisions based on lean thinking. This transformation demands a deep-seated desire to enhance efficiency. Similarly, in Technology Management, it is imperative to embrace the holistic approach and implement it within the organization. All processes within Technology Management must be firmly embedded in the structures to initiate optimization efforts. Given these parameters, it is advisable to consider the combination of both disciplines and initiate the implementation of Lean Technology Management. Consequently, an organization can evolve sustainably towards becoming a Lean Company, continually adapting this objective to changing conditions. Ensuring necessary flexibility requires the implementation of a concept as described in Chapter 4.3.1 Lean Technology Management.

Following is the description or supplement to the advanced model. Two models have been utilized as the foundation for the Advanced Lean Technology Management Model in this work. The cornerstone is laid by Schuh's framework for Technology Management, detailed in Chapter 2.3.2.1 The regulatory framework according to Schuh and Klappert. Building upon this, a conceptual Lean Technology Management Model is described in Chapter 2.4.4 Adapted Lean Technology Management Model through a Systematic Literature Review. This, in turn, formed the basis for the empirical part of this work. Consequently, in Chapter 4.3.2 Advanced Lean Technology Management Model, the theoretical as well as empirically gained knowledge are integrated into a final Lean Technology Management Model.

The final section of this chapter encompasses Chapter 4.3.3 Lean Company and Leanology, which delineates the objective of evolving into a Lean Company and the resultant developments encapsulated by the newly defined term Leanology.

4.3.1 Lean Technology Management

In Lean Technology Management, the challenge lies in translating the strongly operational perspective of Lean Management to Technology Management. This necessitates defining a kind of translation mechanism, achieved in the work through the definition and application of lean principles. These original lean principles, derived from literature, are depicted in Figure 10 in Chapter 2.4.2 Clustering of lean methods to principles. Furthermore, the newly defined lean principles can also be found in the same chapter under Figure 11. A comparison between the old and new principles is presented in Figure 16.

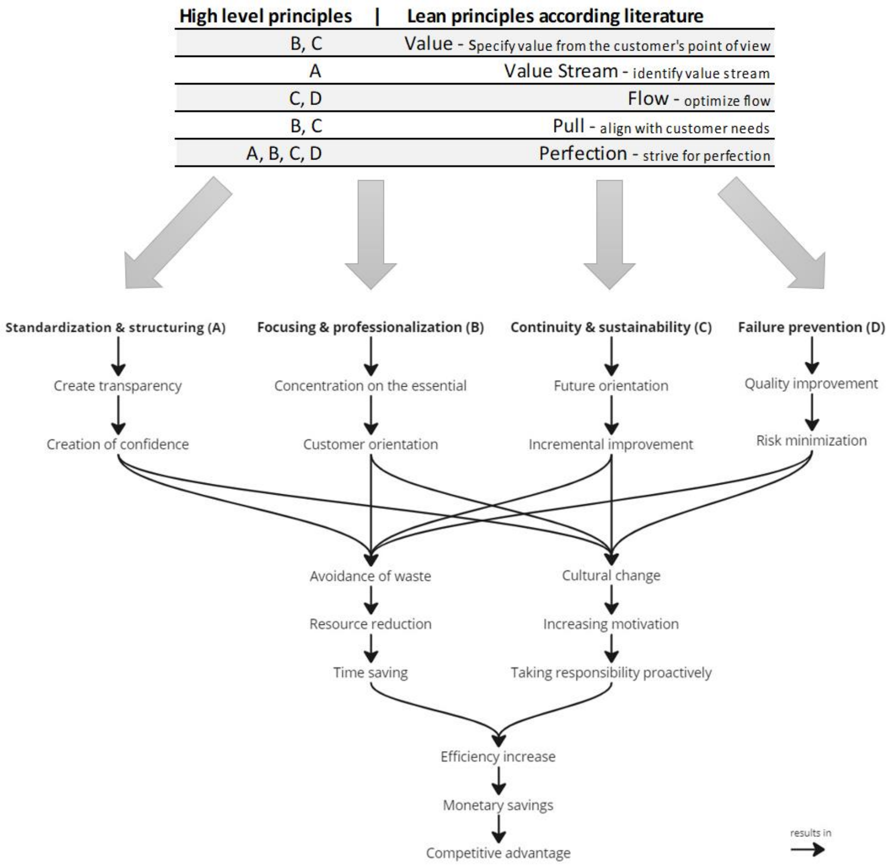

Figure 16: Comparison of lean principles

To apply Lean Management principles effectively to Technology Management, it is essential to comprehend the underlying intentions inherent in the originally defined lean principles and elevate them to a higher conceptual plane. This facilitates their translation into the realm of Technology Management and the subsequent implementation of the underlying methodologies. Table 19 delineates the methods deemed promising. Emphasis should be placed on these methods and their application across various stages of the Technology Management process, guided by the principles. This compilation stems from Figure 15 and Table 18, sorted in ascending order up to Position 6. From Position 7 to 16, prioritization in application should be disregarded initially. Subsequently, methods should be prioritized based on individual requirements for implementation.

Prioritization	***Lean Method***	***Contribute to principle***
1	Kaizen/CIP	A, B, C
2	Visual Control system via KPIs	A, B
3	5S	A, B
4	Failure Mode Effects Analysis	C, D
5	Pareto	B
6	Five whys	B
7-16	Gemba	B
7-16	7 wastes	A, C
7-16	Poka Yoke	D
7-16	Theory of Constraints	B, C
7-16	Just in Time	A, B, C
7-16	ABC	B
7-16	Kanban	A, C
7-16	Six Sigma	C, D
7-16	Overall Equipment Effectiveness	A
7-16	Value Stream Mapping	A, B

Table 19: Propitious lean methods

4.3.2 Advanced Lean Technology Management Model

Given the prior exposition of the model's individual components in Chapter 2.4.4 Adapted Lean Technology Management Model, this section exclusively addresses supplementary elements, expansions, and insights derived from empirical findings relevant to the aforementioned chapter. The final model is shown in Figure 17, followed by explanations of the individual areas of the model.

The primary components of the model entail, firstly, a central emphasis on customer orientation and iterative enhancement driven by feedback loops, facilitating alignment of the enterprise and subsequent optimization via lean principles. Secondly, it involves comprehensive examination of all corporate processes and their interrelations, with particular emphasis on the domain of Technology Management.

The color coding of the model makes it possible to differentiate between the individual areas. The following pages explain these areas and their new features.

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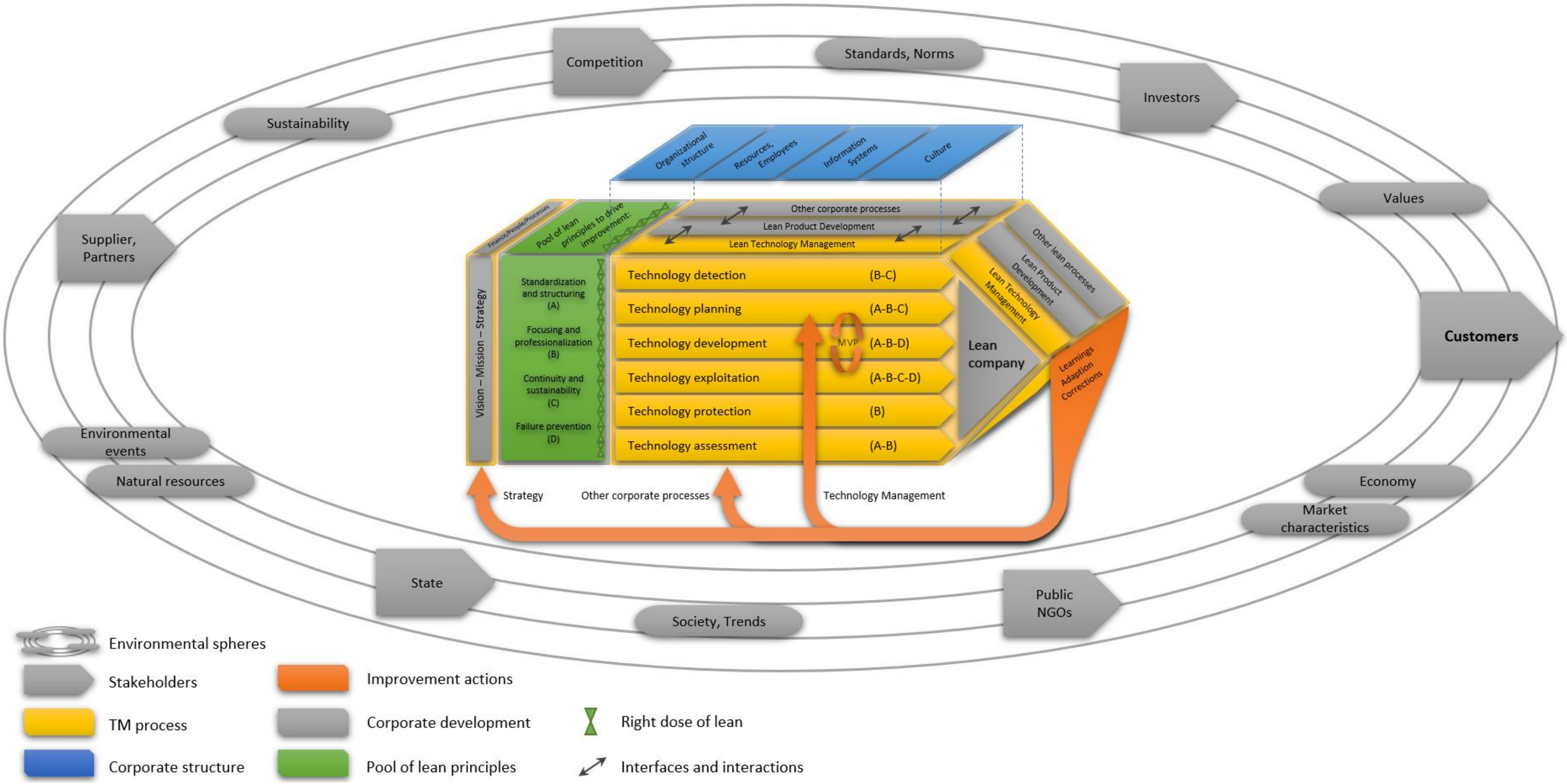

Figure 17: Advanced Lean Technology Management Model

4.3.2.1 Environmental spheres and stakeholders

In Chapter 2.4.4.1 Environmental Spheres and Stakeholders, the environmental spheres and stakeholders are delineated based on theoretical frameworks. Here, adjustments and conclusions are drawn from empirical insights, serving as supplements to the preceding chapter.

A pivotal observation lies in the central focus of the advanced LTMM, which unequivocally centers on customer orientation. It is imperative to foster organizational flexibility to meet customer demands comprehensively, thereby consistently maximizing market penetration. Additionally, an augmentation is discernible within the societal sphere through the incorporation of trends. This strategic move is imperative to ensure the identification and vigilance over critical trends and megatrends, preventing oversight. Furthermore, a refinement is made concerning the natural sphere, delineating it into environmental events and natural resources. Given the escalating frequency of environmental crises and the depletion of resources, these aspects necessitate heightened priority in diverse risk assessments. The sustainability aspect within the natural sphere remains intact, as it is entrusted to the sustainability sphere. Another inclusion pertains to the economic sphere, featuring market characteristics. This addition underscores the significance of specific market dynamics within a company's operational landscape, often superseding broader economic indicators. Notably, a redefinition is observed in stakeholder categorization, whereby employees transition from stakeholders to integral components of the corporate structure. This revision is grounded in the recognition of employees as paramount assets within a company's framework.

4.3.2.2 Technology Management process

In Chapter 2.4.4.2 Technology Management process, the Technology Management process delineated based on theoretical frameworks. Here, adjustments and conclusions are drawn from empirical insights, serving as supplements to the preceding chapter.

The Technology Management process itself remains unchanged; only the terminology of technology detection is slightly generalized to encompass broader activities beyond early technology detection. This shift acknowledges the need for comprehensive technology detection, encompassing both early and later stages, to minimize risks or disadvantages and, conversely, to maximize competitive advantage.

Another addition to the process understanding is that technology planning, technology development, and technology exploitation operate within a smaller, iterative loop. This loop serves to actualize the concept of MVPs and thus enables rapid market feedback generation.

Final evaluation and resulting principles:

In relation to the recommended lean principles for various Technology Management process steps, changes have arisen as a result of empirical data collection. These alterations do not affect every process step, but do impact some, which are described as follows.

Technology detection – In the domain of technology detection, deviations from the recommended lean principles within this segment were identified through empirical analysis. Specifically, principles B and C are augmented in this context, as concentration on focusing & professionalization and continuity & sustainability are deemed crucial. This ensures that only essential technologies are pursued, optimizing their efficiency and relevance over time. Moreover, prioritizing long-term viability and resilience in technological foresight fosters enduring success and a competitive advantage in the industry. Further detailed insights regarding the empirical findings can be found in Chapter 3.4.3.4 Lean Principles and Methods for Technology Management. The conclusive recommendation advocates for Principles B and C, as illustrated in Figure 18.

Technology planning – In the realm of technology planning, empirical analysis did not unveil any deviations pertaining to the recommended lean principles within this segment. The final recommendation advocates for principles A, B, and C, as depicted in Figure 18.

Technology development – In the domain of technology development, deviations from the recommended lean principles within this segment were identified through empirical analysis. Specifically, principle C is replaced by principle A. The shift towards standardization & structuring is paramount as it enables efficient modularization, quantification of reuse rates, substantial reduction in development times, and ensures alignment with customer requirements, quality improvement, risk mitigation, and continuous improvement of technology development processes. Prioritizing these principles thus fosters operational efficiency, customer satisfaction, and sustainable advancement in technological innovation. Further detailed insights regarding the empirical findings can be found in Chapter 3.4.3.4 Lean Principles and Methods for Technology Management. The conclusive recommendation advocates for Principles A, B, and D, as illustrated in Figure 18.

Technology exploitation – In the realm of technology exploitation, empirical analysis did not unveil any deviations pertaining to the recommended lean principles within this segment. The final recommendation advocates for principles A, B, C, and D, as depicted in Figure 18.

Technology protection – In the domain of technology protection, deviations from the recommended lean principles within this segment were identified through empirical analysis. Specifically, there is a reduction in emphasis on principle A, with a focus directed towards principle B. Focusing & professionalization are advocated by various companies for efficient technology protection, emphasizing the need to concentrate efforts on essential areas such as intellectual property (IP) and know-how protection to avoid inefficiencies and ensure cost-effectiveness. By setting priorities and recognizing what truly needs protection, companies can optimize resource allocation and streamline operations in cost-intensive areas such as the patent system. Further detailed insights regarding the empirical findings can be found in Chapter 3.4.3.4 Lean Principles and Methods for Technology Management. The conclusive recommendation advocates for principle B, as illustrated in Figure 18.

Technology assessment – In the domain of technology assessment, deviations from the recommended lean principles within this segment were identified through empirical analysis. Specifically, there is a reduction in emphasis on principles C and D, while principles A and B are prioritized. The prioritization of standardization & structuring and focusing & professionalization is supported by various companies, which emphasize the importance of consistent evaluation standards and the necessity for a logical focus on established goals to ensure comparable and appropriate results. Simultaneously, standardized assessment metrics and a concentrated approach are deemed indispensable for effectively evaluating dedicated objectives. Further detailed insights regarding the empirical findings can be found in Chapter 3.4.3.4 Lean Principles and Methods for Technology Management. The conclusive recommendation advocates for Principles A and B, as illustrated in Figure 18.

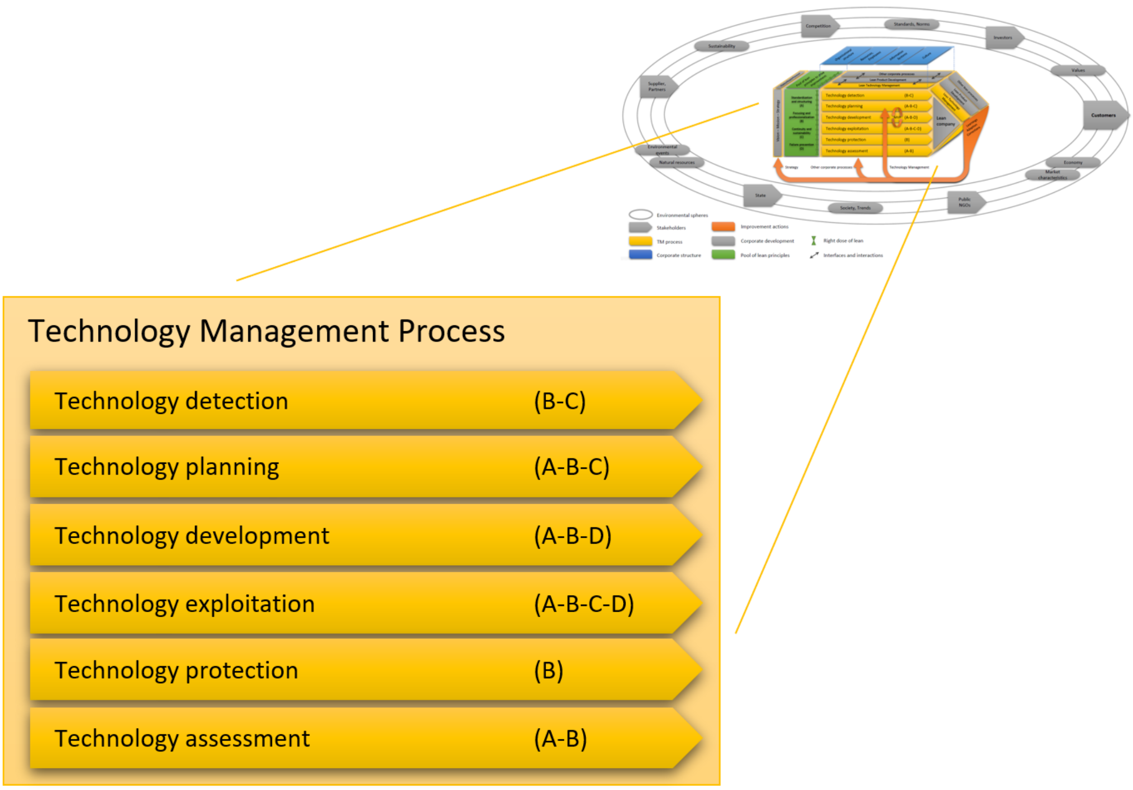

Figure 18: Final assignment of lean principles in the Technology Management process

4.3.2.3 Corporate structure

In Chapter 2.4.4.3 Corporate structure, the corporate structure delineated based on theoretical frameworks. Here, adjustments and conclusions are drawn from empirical insights, serving as supplements to the preceding chapter.

The company structure remains largely unchanged, with a clear focus, as visualized in Figure 17, on the need for the structure to encompass all corporate processes. The four main areas have been supplemented with a focus on the employee component, which is separately outlined in the resources section. As reiterated several times, employees are essential to a company's success, and their expertise is indispensable for the execution of various business processes. In conclusion, an attempt has been made to depict the company structure as a roof overseeing the corporate processes. This ensures that all processes within a company can be carried out and implemented effectively through the desired culture, existing information systems, available resources and employees, and the established structure.

4.3.2.4 Corporate development

In Chapter 2.4.4.4 Corporate development, the corporate development delineated based on theoretical frameworks. Here, adjustments and conclusions are drawn from empirical insights, serving as supplements to the preceding chapter.

It is readily apparent that the vision, mission, and consequent strategy constitute the foundational framework of the company. This primary alignment is imperative for customer-centric focus and serves as the fundamental scaffold for all ensuing organizational activities. Additional domains, including renewal and improvement, have been reorganized under improvement actions, thereby encapsulating their contents through the illustrated feedback loop. Furthermore, the operations domain is not delineated separately but is rather synthesized from a multitude of business processes, visually depicted as comprising various operational facets. As a result, all other processes and workflows from the original sub-area are reflected in the various business processes.

4.3.2.5 Pool of lean principles and right dose of lean

Given the extensive array of lean principles and the resulting variety of methods, which can quickly overwhelm companies, it becomes necessary to incorporate a dosing unit. This dosing unit serves as a barrier between the pool of lean principles and their derived lean methods, ensuring that the recommended lean principles guide the selection of appropriate lean methods for improvement implementation. It is crucial to emphasize the targeted application of lean methods, aligning with lean principles. Attempting to apply all lean principles across all areas would result in waste and counterproductively impact efficiency, contradicting the essence of lean practices and hindering the development to a Lean Company. Furthermore, it is advisable to conduct evaluations, similar to those performed for the Technology Management process and proposed here using A, B, C and D principles, for all other corporate processes. Without such assessments, targeted dosing of lean principles becomes challenging.

4.3.2.6 Interfaces and interactions

Interfaces and interactions among individual corporate processes are essential components for ensuring comprehensive process execution. These interfaces must be meticulously defined, as they represent critical points of friction in meeting customer requirements. Managing the multitude of interfaces across all business processes necessitates structured methodologies. For instance, one approach involves delineating clear responsibilities within the organization and establishing tabular communication interface summaries among various personnel and departments, both internally and externally. However, while the importance of such strategies is recognized, this paper maintains a specific focus on the Technology Management process rather than addressing the entirety of corporate processes. It is imperative not only to create summaries for interfaces but also for the resulting interactions among different corporate processes. This enables a comprehensive understanding of their relevance to the organization, facilitating the ability to prioritize effectively.

4.3.2.7 Improvement actions

An evident yet pivotal modification in the advanced LTMM lies in the integration of a feedback loop or improvement cycle. This adjustment signifies the iterative and adaptive nature of the entire process, emphasizing its responsiveness to customer needs. On one hand, the Technology Management process undergoes iteration in alignment with the minimum viable product (MVP) paradigm. Therefore, optimization through lean thinking is expected to yield significant advantages in the area of time-to-market. It may result in higher market shares achieved by timely market presence, significantly reduced acquisition costs, and increased perceived value of the offered product. On the other hand, supplementary improvement measures, informed by experiences, insights, or necessary corrections, are channeled back into technology planning to enhance its efficacy further. Additionally, a commitment to optimizing all other business processes in line with continuous improvement principles is underscored. This entails the meticulous fine-tuning of processes to ensure ongoing enhancement. Furthermore, in the event of substantial alterations or requisite adjustments, the alignment of the vision, mission, and resulting strategy with prevailing conditions becomes imperative. This adaptive approach is indispensable for steering the organization towards sustainable development as a Lean Company. In essence, the imperative is to seamlessly integrate all improvement initiatives, measures, and necessary adaptations into the respective business processes, ensuring their effective adoption and implementation. This process must be characterized by continuity and sustainability to enable the organization to evolve continually and engender enduring competitive advantages.

4.3.3 Lean Company and “Leanology”

The concept underpinning the endeavor to streamline the Technology Management process is rooted in the notion that by fostering efficiency in this domain, the entire organizational structure can be imbued with lean principles. While not novel, this idea remains profoundly intriguing. A Lean Company, as delineated in the Advanced Lean Technology Management Model depicted in Figure 17, is one that strategically incorporates lean principles across all facets, categorized as A, B, C, and D. This ideal scenario is not a static event but rather an ongoing journey, necessitating unwavering commitment and sustained efforts throughout the organization. It is a journey marked by perpetual refinement, where the pursuit of perfection serves as the guiding beacon. Indeed, the pursuit of continuous improvement and the quest for perfection are intrinsically positive endeavors, driving organizational growth and fostering a culture of innovation and excellence. As such, it is imperative to recognize that the journey towards optimal efficiency is an iterative process, where incremental gains are celebrated, and the ethos of improvement permeates every aspect of organizational functioning. With the assumption that at least in the area of Technology Management the pool of lean principles is applied, and the result is a new technology and subsequent new, innovative, in the best case even disruptive products, then one speaks of a **Leanology**. A technology, which was developed by a company, which works based on the Lean Technology Management Model. As previously outlined, the application of lean principles not only to Technology Management but also to other corporate processes has the potential to catalyze the transformation of the entire organization into a Lean Company. This holistic integration of lean methodologies across various facets of the company fosters a culture of efficiency and continuous improvement at every level. By extending the principles beyond Technology Management to encompass other domains, such as production, supply chain management, innovation management, product development, and sales, the organization undergoes a comprehensive optimization process – the full list of other corporate processes is shown in Table 8. This holistic approach ensures that lean principles become ingrained in the organizational DNA, guiding decision-making and driving performance improvements across the board. Consequently, the company evolves into a lean entity characterized by streamlined processes, minimized waste, enhanced productivity, and a relentless pursuit of excellence.

4.3.4 Proposed implementation of the LTMM

The implementation of this model can be fundamentally achieved by leveraging the four lean principles alongside the corresponding methodologies. An overview is shown in Figure 19, which provides a rough representation of the necessary steps.

The process is structured as follows:

1. **Analyze, define, and adapt relevant processes:**
   Initially, it is critical to conduct a thorough analysis of existing processes to identify inefficiencies, redundancies, or areas requiring improvement. This step involves defining the scope and objectives of each process and making necessary adaptations to align them with the overarching goals of lean principles. The focus is on streamlining operations, eliminating waste, and ensuring that each process contributes to value creation.

2. **Supplement missing processes based on Technology Management according Figure 18:**
   Once existing processes have been analyzed and adapted, the next step is to identify and address any gaps. Missing processes should be supplemented using the different process steps of Technology Management described in this thesis, ensuring that all technological tools and innovations necessary for efficient operation are integrated. This step is crucial for maintaining competitiveness and leveraging technology to enhance process efficiency and effectiveness.

3. **Review the new process landscape and align with LTMM, ensuring completeness according Figure 17:**
   After refining and supplementing the process landscape, a comprehensive review is necessary. This review should compare the new processes with the LTMM to ensure alignment and completeness. The LTMM serves as a benchmark for evaluating the entirety of the implemented processes and ensures that all critical areas are covered and that the process landscape is coherent and fully developed.

4. **Implement and embed the six methods of Table 19 into individual processes and activities:**
   The next step involves the actual implementation of the six specific methods within each identified process and activity. Embedding these methods is essential for ensuring that lean principles are not only applied theoretically but are practically integrated into daily operations. This step requires careful planning and execution to ensure that the methods are adapted to the specific needs of each process, and that they effectively contribute to overall process improvement.

5. **Train all affected employees and engage them in the change process:**
   Successful implementation hinges on the involvement and understanding of all affected employees. This step involves providing comprehensive training to ensure that all team members are equipped with the knowledge and skills needed to work within the new process framework. Additionally, it is vital to actively engage employees in the change process, fostering a sense of ownership and commitment to the new methodologies.

6. **Define responsibilities, activities, and interfaces, with consensus on changes:**
   Clear definition of responsibilities, activities, and interfaces is essential for smooth operation and collaboration across the organization. This step involves detailing who is responsible for each aspect of the process, what activities are required, and how different processes and teams will interact. Achieving consensus on these definitions through collective agreement ensures that all parties are aligned and committed to the changes.

7. **Gradual implementation and adjustment of processes by responsible parties:**
   Rather than implementing all changes at once, a phased approach is recommended. This allows for gradual adaptation and refinement of processes, providing opportunities to identify and address challenges as they arise.

Responsible parties should oversee the implementation, making necessary adjustments to ensure that the processes evolve in alignment with lean principles according to Figure 16.

8. **Regular review and adjustment in response to problems:**
   Continuous improvement is a core tenet of lean methodology. Regular reviews should be conducted to assess the performance of the implemented processes and identify any emerging issues. This ongoing assessment allows for timely adjustments, ensuring that the processes remain effective, efficient, and aligned with organizational goals. Regular feedback loops and iterative improvements are crucial for maintaining the long-term success of the implemented LTMM.

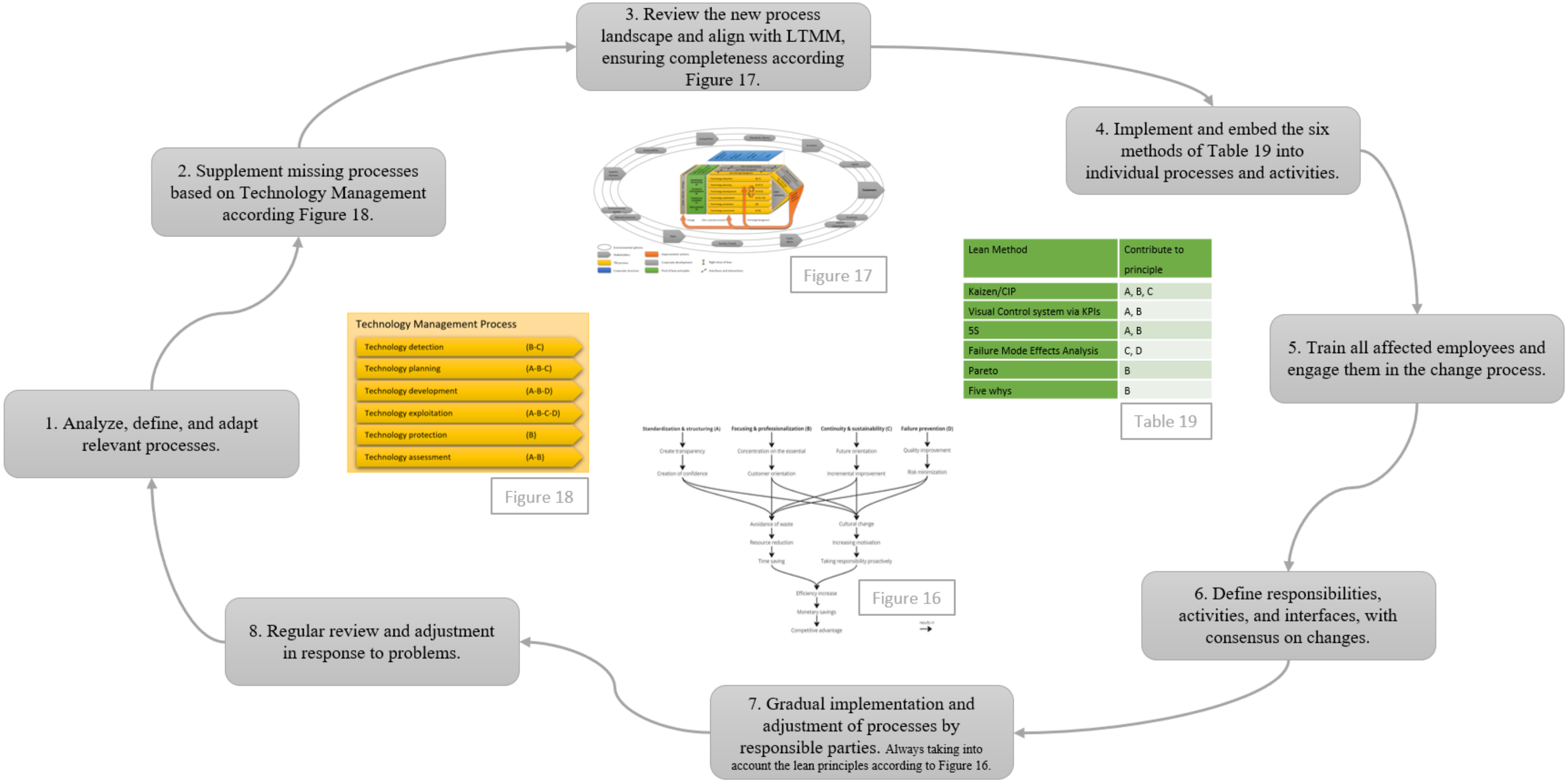

Figure 19: Proposed implementation of the LTMM

4.4 Implications

The results of this study yield several implications that can be derived theoretically, practically, and in terms of the developed model. This work examines the domains of Lean Management and Technology Management, as well as their potential synergies in the form of Lean Technology Management. The emphasis is clearly placed on the integration of both concepts. Based on theoretical models and empirical data, a Lean Technology Management Model has been developed. Chapter 4.4.1 Theoretical implications delves into the theoretical implications derived from the literature, while Chapter 4.4.2 Managerial implications and recommendations for companies elucidates the practical implications. Chapter 4.4.3 Implications in terms of the LTMM addresses the implications associated with the Lean Technology Management Model.

The theoretical implications of this work offer insights into existing knowledge gaps and extend the understanding of the interactions between Lean Management and Technology Management. Through the integration of various theoretical approaches, new insights have been gained, contributing to the further development of the theoretical framework for Lean Technology Management. On a practical level, the findings of this study provide valuable insights for executives and practitioners in organizations who are striving to integrate lean principles with Technology Management to enhance efficiency and competitiveness. These practical implications range from designing effective business processes to optimizing technology exploitation through support of lean initiatives. Additionally, the insights into the implications of the Lean Technology Management Model provide a foundation for further research and development in this area, by identifying potential application areas and challenges that may arise in the implementation of the model. It is noted that further empirical studies are necessary to assess and validate the validity and applicability of the proposed model in various organizational contexts.

4.4.1 Theoretical implications

The present study opens up new perspectives and enhances the existing understanding in the research literature on multiple levels. Specifically, it provides significant insights that contribute to the advancement of the theoretical framework. A notable contribution lies in the fact that the study enables a more comprehensive examination of the underlying mechanisms, supplementing and expanding upon prior assumptions. In relation to the existing literature, the results or findings of this study lead to the following extensions and innovations:

Lean management as a chaotic and unstructured field

This study contributes to a clearer structuring and definition of the Lean Management topic by identifying and describing its essential core themes. Through a systematic literature review, the fundamental principles of Lean Management have been delineated and presented within a coherent framework. This facilitates readers in grasping the essence of Lean Management and comprehending its underlying principles within a concise scope. Furthermore, the study underscores the imperative to view Lean Management not merely as a collection of methods, but as a cultural transformation necessitating the internalization of lean principles throughout the entire team to achieve sustainable improvements. Emphasizing the holistic lean philosophy serves to deepen understanding of the intricacies of Lean Management and facilitate its application across diverse organizational contexts.

Generalization of lean principles

In the context of Lean Management, the previously operationally-focused lean principles have been generalized to enhance their applicability across a broader spectrum of organizations and business sectors. This adaptation was achieved through the identification and abstraction of the fundamental principles of lean thinking, which remain pertinent irrespective of specific operational processes. Consequently, the perspective and underlying comprehension have been elevated to a broader level of consideration. Through this generalization, constraints previously associated with operational domains have been alleviated, thus expanding the scope of potential applications and fostering innovation in other areas. These generalized lean principles provide a framework enabling organizations to leverage the essence of lean thinking across diverse contexts and to advance continuous improvement initiatives.

Understanding of Technology Management

In addition to the existing literature, this study contributes to the understanding of Technology Management by highlighting that many companies lack clarity regarding the scope of this management discipline. Technology Management largely remains unrecognized as a distinct discipline and often remains overlooked by many organizations, existing somewhat "between the lines," which leads to its underappreciation. This clarification is crucial to emphasize the relevance of Technology Management as an independent discipline and ensure its adequate consideration within companies and organizations. Furthermore, the study underscores the challenges that companies face when striving to effectively harness the potential of technology. It provides avenues for improved integration of Technology Management into entrepreneurial decision-making processes. Through this in-depth analysis, awareness of the significance of Technology Management is heightened, and its potential for creating sustainable competitive advantages is emphasized.

Fundamental joint examination of both subject areas

A key contribution of this work lies in the integration of various theoretical approaches that have hitherto been treated as separate strands in the literature. Through synthesizing these approaches, a more holistic perspective on the subjects of Lean Management and Technology Management emerges, leading to enhanced coherence and integration within the research field. The concept of Lean Technology Management, resulting from this integration, represents an innovative approach that transcends previous boundaries between Lean Management and Technology Management, opening up new avenues for effectively utilizing technology for process optimization and value creation. This holistic approach provides a robust foundation for future research and practice in the realms of organizational development and innovation management.

4.4.2 Managerial implications and recommendations for companies

The empirically gathered data from my dissertation yield valuable insights and findings with direct implications for practitioners and businesses. Specifically, the data demonstrate that certain practices or approaches in corporate management are more successful than others. Furthermore, the collected data underscore the significance of specific factors or strategies for the long-term success of a company. For instance, they indicate that a stronger focus on customer needs or effective exploitation of technology can have significant positive impacts on corporate performance. These insights provide practitioners with valuable perspectives to adapt their business strategies accordingly and respond to changing market conditions. Consequently, the following implications arise for practitioners:

Viewing Lean Management as a philosophy rather than a cost-cutting aid

In many companies, Lean Management is mistakenly viewed solely as a cost-reduction tool, leading to a misunderstanding of its underlying philosophy. Instead of being perceived as a cultural shift and a continuous improvement process, Lean Management is often seen as a means to reduce personnel, resulting in a loss of motivation and productivity. To successfully implement Lean Management, it is therefore crucial to impart to employees an understanding of the underlying principles and to foster a positive attitude towards change. This includes continuous training and awareness-building in lean methods to ensure that the lean philosophy is ingrained throughout the organization and actively embraced by all employees. Only through this approach can sustainable successes be achieved and a positive turnaround be generated.

Technology Management as a core competence

The findings of the dissertation underscore the necessity for companies to consider Technology Management as a core competency in order to remain competitive in the long term. This entails a strategic orientation towards the effective utilization and development of technology as a driver for innovation and growth. Companies should not view Technology Management as an isolated function but rather as a cross-cutting task that affects all areas and levels of the organization. This requires a comprehensive integration of Technology Management into the corporate strategy and culture, as well as continuous investment in technology competencies and infrastructure. It is essential for companies to focus on Technology Management in order to achieve sustainable success and longevity.

Clarifying and defining terminology within one's own company

The lack of clarity and agreement regarding the definitions of Lean Management and Technology Management within a company leads to misunderstandings, conflicts, and inefficient work processes. A poignant example of this is the ambiguity between product development and technology development within companies. To overcome these challenges, it is crucial to establish clear and consistent definitions for relevant terms and ensure they are understood and accepted by all employees. This requires a transparent communication process along with training and educational materials to ensure that all employees have a shared understanding of the terms. Furthermore, it is important to regularly review the effectiveness of these definitions and adjust them as needed to ensure they align with the changing requirements and developments within the company.

Implementing Lean Technology Management in practice

The implementation of Lean Technology Management requires a structured approach tailored to the specific needs and challenges of a company. It is essential to identify and understand the key methods and principles of Lean Technology Management to enable effective execution. Companies can benefit from the overview of methods presented in the dissertation (see Table 19) and principles (see Figure 16) to facilitate the initiation of Lean Technology Management and identify optimization potentials. Furthermore, establishing a continuous improvement process is crucial to evaluate and adapt the effectiveness of Lean Technology Management over time. This necessitates an open feedback culture and a willingness to adjust to new challenges and circumstances. Ultimately, successful implementation of Lean Technology Management can contribute to improved competitiveness and long-term business success.

4.4.3 Implications in terms of the LTMM

The impacts stemming from the application of the Lean Technology Management Model and its resultant impacts are delineated herein based on a synthesis of theoretical frameworks and empirical evidence. As the LTMM has yet to be implemented within any enterprise, the discourse herein is primarily grounded in logical deductions and empirical observations. Consequently, the overarching effect of deploying the LTMM manifests in a notable augmentation of operational efficiency and effectiveness throughout the entire organizational spectrum, alongside the attainment of a sustainable competitive advantage.

These enhancements derive from the deliberate and sustainable implementation of lean principles and associated methodologies. While the focal point primarily pertains to the optimization of the Technology Management process, the extensibility of lean principles to encompass all organizational workflows is contingent upon judicious prioritization and meticulous assessment to ensure targeted waste reduction.

Further resultant effects that **positively** influence operations include:

- The establishment of transparent organizational structures and delineation of roles and responsibilities, coupled with precise interface definitions, serves as the bedrock for streamlined operations. Standardization emerges as the linchpin for ensuring success in routine workflows.
- A well-founded strategic footing serves as the fulcrum for guiding all ensuing activities, thereby furnishing the organization with a clear trajectory and engendering a sense of assurance. Consequently, the organizational vision and its long-term viability are conscientiously integrated into all operational endeavors, thereby ensuring directional alignment.
- A resulting competitive advantage arises from monetary savings, reduced time-to-market for new technologies and resultant products, as well as satisfied customers and employees due to high-quality standards in targeted areas based on defined lean principles.

Further resultant effects that **negatively** impact operations include:

- Lack of measurability of subjective successes and failures can lead to potential issues regarding necessary adjustments, thereby hindering the derivation of improvement measures. This weakens the feedback loop and impedes the effect of continuous improvement.
- Excessive application of lean thinking leads to over-standardization and a rigid, inflexible organization incapable of responding to customer demands. The dosage of lean thinking is crucial and must be continually adjusted based on situational requirements.
- A too-radical introduction of such a complex model can quickly destabilize a stable organization, leading to overload. Consequently, motivation decreases, resulting in deteriorated overall performance and accumulation of inefficiencies and problems. Consequently, the proposed steps, which are explained in Chapter 4.3.4 Proposed implementation of the LTMM, should be closely followed during the implementation process.

5 Summary and Outlook

The aim of this dissertation was to bridge the gap between Lean Management and Technology Management by applying principles of Lean Management to the realm of Technology Management. This amalgamation resulted in a novel concept termed Lean Technology Management, which is defined through the development of a foundational model. The findings and implications of this research have been extensively expounded upon in the preceding chapter. This concluding chapter serves as a synthesis of the entire study, presented in Chapter 5.1 Summary of the research, followed by a critical discussion of research limitations in Chapter 5.2 Research limitations. Finally, potential areas for further investigation are identified and discussed in Section 5.3 Future research.

5.1 Summary of the research

The fusion of Lean Management and Technology Management holds significance not only in theory but also presents practical applications for organizations, particularly in rapidly evolving technological environments. By integrating lean principles, companies can optimize their processes, reduce waste, and enhance their capacity for innovation. This dissertation aims to deepen understanding of implementing lean methods in technology-based organizations while bridging the gap between traditional Lean Management and modern Technology Management. The developed model of Lean Technology Management offers a systematic approach for applying lean principles in technology-oriented organizations. It prioritizes maximizing efficiency and value enhancement through the exploitation of technology and lean methodologies. By leveraging this model, organizations have the potential to gain competitive advantages and bolster their market position.

The thesis is fundamentally divided into four main sections, which are clearly depicted in Figure 2, illustrating their structure. The individual chapters of this thesis are briefly explained as follows:

Chapter 1 provides an explanation of the theoretical relevance of the work and describes the research gaps. Additionally, it elucidates the descriptive and empirical research endeavor, as well as formulating the research questions. Furthermore, Chapter 1 outlines the structure of the thesis and explains the research methods employed.

Proceeding to **Chapter 2**, all relevant theoretical knowledge for the thesis is gathered and described through a Systematic Literature Review following Saunders' methodology. This chapter fundamentally engages with the topic by compactly summarizing existing knowledge within each thematic area. These two thematic areas are defined under 2.2 Lean Management and 2.3 Technology Management. In the realm of Lean Management, an attempt is made to provide a concise overview of this extensive subject by focusing on core statements and principles. In the domain of Technology Management, the focus lies on individual sub-areas and processes, which are described in detail. Based on this theory-based foundation, a concept of potential integration is described under 2.3 Lean Technology Management, and an adapted Lean Technology Management Model is developed. These three parts form the basis for Chapter 3, as well as for the development of the questionnaire for conducting the empirical investigation through expert interviews.

In **Chapter 3**, all empirically collected data is analyzed and evaluated. The empirical data were gathered through expert interviews conducted in 29 different companies. Data analysis followed the 7-phase method described by Kuckartz and Rädiker, based on a Content-structuring Qualitative Content Analysis. This analysis yielded valuable insights for refining the Lean Technology Management concept and creating an Advanced Lean Technology Management Model.

Following is **Chapter 4**, which describes all insights, contributions, and implications. It delineates the conclusion of the topic under 4.2 for Lean Management and Technology Management, and under 4.3 for Lean Technology Management. Subsequently, theoretical, practical, and model-related implications are described under 4.4.

Finally, **Chapter 5** presents a summary of the thesis, including its limitations and potential future research endeavors. **Chapter 6** lists all references cited in the thesis, while **Chapter 7** provides all appendices, such as the questionnaire, the codebook, and additional figures from the empirical data collection.

Lastly, a summary of the thesis is presented in Table 20, summarizing the goals, main findings, and contributions.

Objective	Description of the areas of Lean Management that are suitable for application in Technology Management.
Research Question 1	Is the concept of Lean Management useful for Technology Management?
Main findings	• Lean management as a chaotic and unstructured field • Fundamental joint examination of both subject areas • Viewing Lean Management as a philosophy rather than a cost-cutting aid
Contributions	Presentation of a Lean Technology Management concept, illustrating fundamental measures for the application of Lean Management in Technology Management. Generalizing lean principles for application in Technology Management enables the utilization of established methods and approaches from the lean domain in complex and rapidly evolving technological landscapes. By integrating lean principles into Technology Management, organizations can enhance their innovation capabilities, reduce costs, and bolster their competitiveness in the market.

Objective	Creation and development of a Lean Technology Management Model for use in companies.
Research Question 2	How can the Lean Technology Management Model support the company?
Main findings	• Clarifying and defining terminology within one's own company • Generalization of lean principles • Technology Management as a core competence
Contributions	Companies can leverage the model originating from this study as a guiding framework for enhancing efficiencies in technology-related processes. Moreover, they can implement the prescribed lean methodologies to drive improvements and foster innovation. This model provides a structured approach for organizations to streamline their technological operations, reduce waste, and maximize value delivery. By embracing lean principles outlined in the model, companies can achieve greater agility, cost-effectiveness, and competitive advantage in today's rapidly evolving technological landscape.

Table 20: Summary of the research contributions

5.2 Research limitations

Although the results of this research are promising, there are nevertheless some limitations that need to be considered. For example, the transferability of the developed model to different industries or company sizes may be limited. Furthermore, external influencing factors such as changing market conditions or regulatory frameworks could affect the implementation of Lean Technology Management.

As the investigation was conducted by a single researcher, both data collection and analysis were subject to researcher bias. Among the resulting limitations, access to articles, journals, and books was not unrestricted, thereby preventing a comprehensive review of all relevant literature. Additionally, only one person was interviewed from the 29 different companies, and there was no assessment of the suitability of each interviewee. Furthermore, only interviews with 29 different companies were conducted, limiting the diversity of perspectives. Although various industries and company sizes were considered, the data was confined to the sample of companies, which may restrict the generalizability of the study findings. It is noteworthy that data coding was performed by a single researcher, with no second person verifying the codes, and the code system was also created by a single researcher. While the methodology adhered to the guidelines outlined by Kuckartz and Rädiker, there was no second person to verify the data. Furthermore, the limitation to a single researcher may have potentially led to a biased perspective, as different researchers may have had different interpretations of the data and results. This bias could have resulted in certain aspects of the research not being adequately considered or alternative explanations not being fully explored.

Moreover, the limited number of companies included in the study may restrict the diversity of organizations and industries represented by the results. The selection of companies may also introduce some bias, as companies volunteering to participate may have certain characteristics that differ from those of the general business population.

Another potential limitation lies in the possibility of information bias in expert interviews, as responses may have been influenced by personal opinions, biases, or the desire to portray a positive image of their company or practices. Additionally, language or cultural differences between the researcher and interviewees could lead to misunderstandings or communication issues that may compromise the validity of the collected data.

It is also important to note that while all relevant literature was considered, limited access to certain less crucial sources may have resulted in their exclusion from the presentation of the theoretical background. Additionally, the choice of a specific theoretical framework or model for data analysis may have restricted the diversity of interpretations, as alternative perspectives may not have been sufficiently explored.

Despite these limitations, all steps of the research process were conducted to the best of the researcher's knowledge and ability, with maximum transparency and due diligence. However, it is recommended that future research efforts take these limitations into account and identify potential methods to improve the validity and reliability of the results.

5.3 Future research

In terms of future research, numerous opportunities arise for further exploration of the subject matter. One promising direction could involve investigating specific applications of Lean Technology Management across various industries. This could entail conducting case studies to analyze the effectiveness and adaptability of the lean approach in different contexts. Furthermore, the development of a detailed implementation plan for Lean Technology Management, both at the strategic and operational levels, would be highly desirable for companies. By formulating such implementation strategies, organizations could better address the challenges and opportunities associated with the integration of lean principles into their technology and business processes.

Moreover, studies evaluating the long-term effects of Lean Technology Management on organizational performance could be highly beneficial. This may involve examining metrics such as efficiency, quality, customer satisfaction, and financial performance to assess the long-term benefits and ROI of implementing lean practices. Another promising research direction could involve investigating the impact of a Leanology on companies' innovation capabilities to understand how lean approaches foster and support innovation.

Finally, the continuation of applying Lean Management principles to all other management disciplines paves the way for the creation of a Lean Company that integrates efficiency and innovation in all aspects of its business operations. This holistic perspective provides a solid foundation for future research and practice in the fields of organizational development and Technology Management, as it helps address the complexity and dynamics of modern companies and strengthens their competitiveness.

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7 Appendix

7.1 Questionnaire on Lean Technology Management

For this interview, the following definition of Lean Management and Technology Management applies:

- **Lean Management:** Focus is on continues improvement by trying to create more value for the customer while using less resources. Lean Management is a way of thinking to concentrate on value creation.

- **Technology Management:** Technology Management can be seen as part of corporate management, which is intended to ensure the sustainable development of technologies in the company and secure a long-term competitive advantage.

1. How is Lean Management organized in your company?

2. How is Technology Management organized in your company?

3. What opportunities and risks do you see in the application of lean methods in Technology Management?
   a. Examples opportunities?
   b. Examples risks?

4. In your opinion, which Technology Management tasks have the greatest potential for applying lean thinking?
   a. Do you see an opportunity to apply lean methods here?
   b. Examples?

From question 4, the focus is on the model.

5. Which lean methods are you familiar with?
   a. Table 1 is to be filled in please.

6. Which lean methods are used in your company?
   a. Table 1 is to be filled in please.

Explanation of the newly defined lean principles based on Table 2.

7. In which phase of the Technology Management process does it make sense to apply the different lean principles (A, B, C, D) in your opinion?
   a. Table 3 is to be filled in please.
   b. Why?

8. Please mark the evaluation of the lean method for the Technology Management process step which, in your opinion, does not seem to fit.
   a. Table 4 is to be filled in please.
   b. Why not?

9. Do you see any missing areas/processes in the Lean Technology Management Model?
   a. See Figure 1 – which ones?

10. Where do you see advantages in applying the model in your company?

11. What do you think would be challenges in applying the model?

- Explanation of Table 1: An adapted form of Table 6 from this paper was used for this purpose.
- Explanation of Table 2: The explanation from Chapter 2.4.2 Clustering of lean methods to principles was used for this purpose.
- Explanation of Table 3: The six process steps of Technology Management were shown here.
- Explanation of Table 4: An adapted form of Table 6 from this paper was used for this purpose.
- Explanation of Figure 1: Figure 12 from this paper was used for this purpose.

7.2 Codebook

List of Codes/Categories	Coding rule	Frequency
Total Code system		1221
Organization of Lean Management	**All information of how Lean Management is organized.**	**54**
Organized across the board	Lean Management is clearly and unambiguously structured throughout the company, it is organized as a whole and corresponding processes are in place and lived.	19
Partially organized according to need	Lean Management is partially organized in the company, depending on the occasion, as needed, and sub-processes are in place and lived.	24
Not organized at all	Lean Management is well known, but there are no clear responsibilities and structures for the topic as well it is not organized and there are no processes for it in place.	6
Competence of Lean Management in companies	All information regarding the existing competencies of companies on the subject of Lean Management.	0
Know-How of Lean Management	All information regarding the available know-how as well as possible sources of supply.	14
Understanding of Lean Management	Explanations of what is meant by Lean Management.	15
Naming of Lean Management in companies	Definitions of how lean management is termed in companies.	10
Areas in which Lean Management is applied	Different areas and departments in which Lean Management is applied in companies.	0
Almost all areas	Application of Lean Management in the all areas.	14
Individual areas	Application of Lean Management in the office area.	34
Effects of Lean Management	Effects resulting from the application of Lean Management in the company as well as good examples of Lean Management.	16

Limited application possibilities	Explanations of poor applicability.	3
Potentials for optimization via the application of Lean Management	Identification and explanation of potentials for optimization through the application of lean management.	8
Organization of Technology Management	**All information of how Technology Management is organized.**	**64**
Organized across the board	Technology Management is clearly and unambiguously structured throughout the company, it is organized as a whole and corresponding processes are in place and lived.	25
Partially organized according to need	Technology Management is partially organized in the company, depending on the occasion, as needed, and sub-processes are in place and lived.	13
Not organized at all	Technology Management is well known, but there are no clear responsibilities and structures for the topic as well it is not organized and there are no processes for it in place.	7
Competence of Technology Management in companies	All information regarding the existing competencies of companies on the subject of Technology Management.	0
Know-How of Technology Management	All information regarding the available know-how as well as possible sources of supply.	8
Distribution of information within the company	All information about the distribution of information in the company, weaknesses, strengths, etc.	8
Benchmarking in Technology Management	All information on the topic of benchmarking in technology management.	8
Potentials for improving Technology Management		7
Areas of Technology Management applied	Areas of Technology Management that are applied in companies.	0
Technology detection	All information about technology detection activities in companies.	25
Technology planning	All information about technology planning activities in companies.	20
Technology development	All information about technology development activities in companies.	14
Technology exploitation	All information about technology exploitation activities in companies.	26

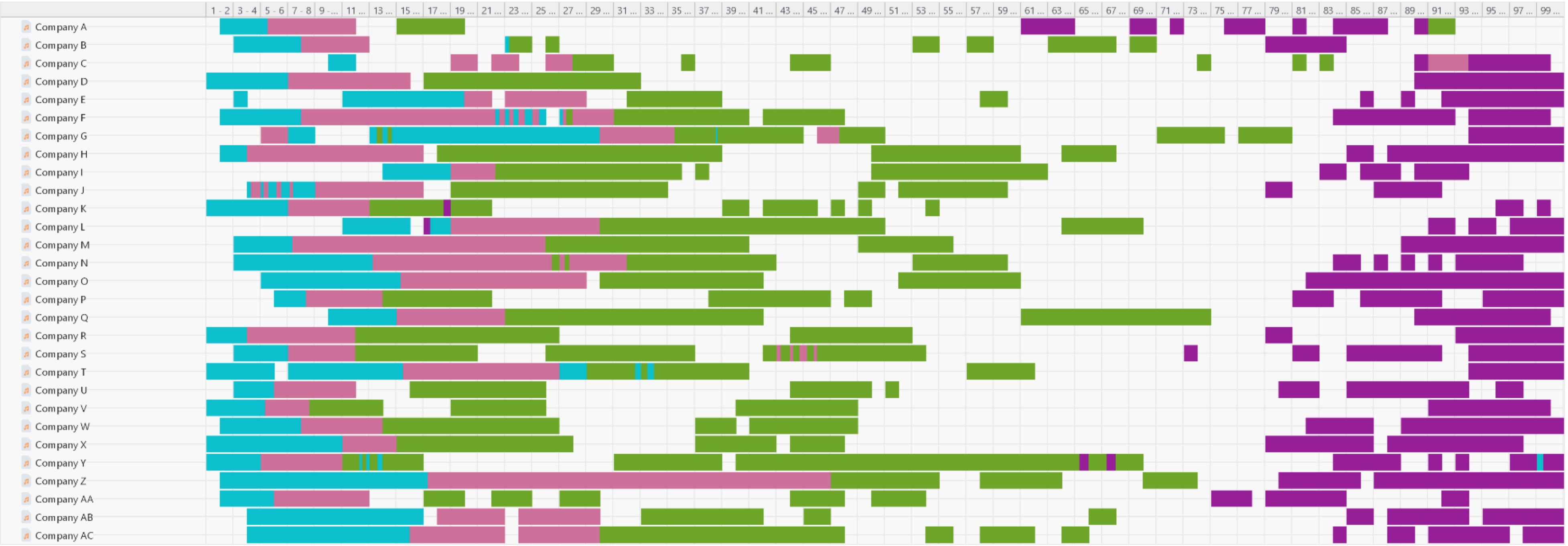
Technology protection	All information about technology protection activities in companies.	5
Technology assessment	All information about technology assessment activities in companies.	5
Application of lean principles or methods in Technology Management	**All information of possible applications of lean principles or methods in Technology Management.**	**138**
Improvement barrier in Technology Management	Obstacles to improvement that companies have to contend with.	0
Social, cultural behavior	Obstacles of improvement that are connected with the social and cultural behavior of the employees.	6
Industry related	Obstacles of improvement that are connected with the industry the company is operating in.	3
Process related	Obstacles of improvement that are connected with process limits.	5
High investment effort	Obstacles of improvement that are connected with high effort.	2
Greatest potential with lean thinking in Technology Management	Greatest potential with lean thinking in Technology Management.	0
All segments of Technology Management	Greatest potential with lean thinking in all Technology Management segments.	10
Technology detection	Greatest potential for lean thinking in technology detection.	7
Technology planning	Greatest potential for lean thinking in technology planning.	3
Technology development	Greatest potential for lean thinking in technology development.	8
Technology exploitation	Greatest potential for lean thinking in technology exploitation.	12
Technology protection	Greatest potential for lean thinking in technology protection.	0
Technology assessment	Greatest potential for lean thinking in technology assessment.	1
Risks in the application of lean methods in Technology Management	Risks in the application of lean methods in Technology Management	39
Opportunities in the application of lean	Opportunities in the application of lean methods in Technology Management.	40

methods in Technology Management		
MVP		6
Lean principles or methods for Technology Management	Which lean principles and/or methods do the interviewees see in Technology Management?	0
Lean in technology detection	Which lean principles and/or methods do the interviewees see in technology detection?	36
Lean in technology planning	Which lean principles and/or methods do the interviewees see in technology planning?	25
Lean in technology development	Which lean principles and/or methods do the interviewees see in technology development?	28
Lean in technology exploitation	Which lean principles and/or methods do the interviewees see in technology exploitation?	35
Lean in technology protection	Which lean principles and/or methods do the interviewees see in technology protection?	21
Lean in technology assessment	Which lean principles and/or methods do the interviewees see in technology assessment?	27
Lean Technology Management Model	**All model related content and comments.**	**123**
Inputs for the model	All feedback and comments regarding the model.	0
Measurability of success	Measurability of success through the model.	1
Application of the model	Notes and recommendations regarding the application and roll-out of the model in companies.	5
Depending on the maturity of a company	Application of the model in dependency of the maturity of a company.	3
Interrelationships and interactions in a company	Information on the interrelationships and interfaces of a company in relation to the model.	9
Graphic input	Graphic input and possible visual suggestions for the model.	41
Knowledge management	All information and tips on knowledge management in companies in relation to the model.	4
Target, strategy, mission, vision	All topics relating to goals, strategy, mission and vision with regard to the orientation of the model.	14
Comments regarding the lean principles	Comments regarding the lean principles.	3

Right doses of lean	Comments and tips on the right dose of lean.	6
Importance of culture, employees	Feedback on the model in relation to the culture of a company.	17
Clarification of terms	Importance of clearly defining and creating a uniform understanding of different terms within the company.	3
Challenges in applying the model	All possible challenges in applying the model in a company.	49
Advantages in applying the model	All possible advantages in applying the model in a company.	38

Table 21: Codebook

7.3 Graphical representation of code frequencies across all documents



Codes	1221
Organization of Lean Management	217
Organization of Technology Management	236
Application of lean principles or methods in Technology Management	452
Lean Technology Management Model	316

Table 22: Graphical representation of code frequencies across all documents

7.3 Graphical representation of code frequencies across all documents

Figure 20: Code Cloud

8 Epilog

Als ich mich auf die Reise durch die Tiefen dieses Forschungsfeldes begab, war mir nicht bewusst, welch immenses Meer an Erkenntnissen und Herausforderungen mich erwarten würde. Durch unzählige Stunden der Reflexion und des Diskutierens habe ich Einblicke gewonnen, die weit über das hinausgehen, was ich mir je hätte vorstellen können.

In diesem Epilog möchte ich nicht nur auf die Ergebnisse meiner Dissertation zurückblicken, sondern auch auf die persönliche Reise, die ich während dieses Prozesses durchlaufen habe. Ich erinnere mich an die Momente der Frustration, in denen die Antworten sich zu verstecken schienen, und an die Momente der Euphorie, wenn sich ein Puzzlestück in das Gesamtbild einfügte. Mein treuer Freund und Wegbegleiter Karlheinz hat mich stehts gefordert und ermutigt weiterzumachen. So hat auch meine Nebentätigkeit, meine Leidenschaft des Unternehmertums, mich stehts aus der Reserve gelockt und einen großen Beitrag zum Ergebnis der Arbeit beigetragen. Der gesamte Prozess hat mich nicht nur intellektuell, sondern auch emotional bereichert.

Als ich nun diese Dissertation abschließe, betrachte ich sie nicht als das Ende meiner Reise, sondern vielmehr als einen Meilenstein auf meinem Weg des lebenslangen Lernens und der Erkundung. Die Fragen, die sich während meiner Forschung ergeben haben, bleiben bestehen, und ich hoffe, dass meine Arbeit dazu beitragen wird, dass auch andere sich ihnen stellen und sie weiterentwickeln.

Ich danke all jenen, die mich während meiner Dissertation unterstützt haben – meiner Frau Lisa, meiner Schwester Bianca, meinen Eltern, meinen Schwiegereltern, meinen Freunden und meinem Doktorvater Prof. Vorbach. Ihre Unterstützung, ihr Rat und ihre Ermutigung haben mich durch die schwierigsten Zeiten getragen und meine Freude in den besten Zeiten geteilt. Möge diese Arbeit nicht nur ein Beitrag zum wissenschaftlichen Diskurs sein, sondern auch ein Anstoß für weitere Erkundungen und Entdeckungen auf diesem faszinierenden Gebiet. In diesem Sinne schließe ich dieses Kapitel und freue mich auf die Abenteuer, die noch kommen mögen.